National Park Service
U.S. Department of the Interior

Geologic Resources Division
Denver, Colorado

Colorado National Monument
Geoindicators Scoping Report

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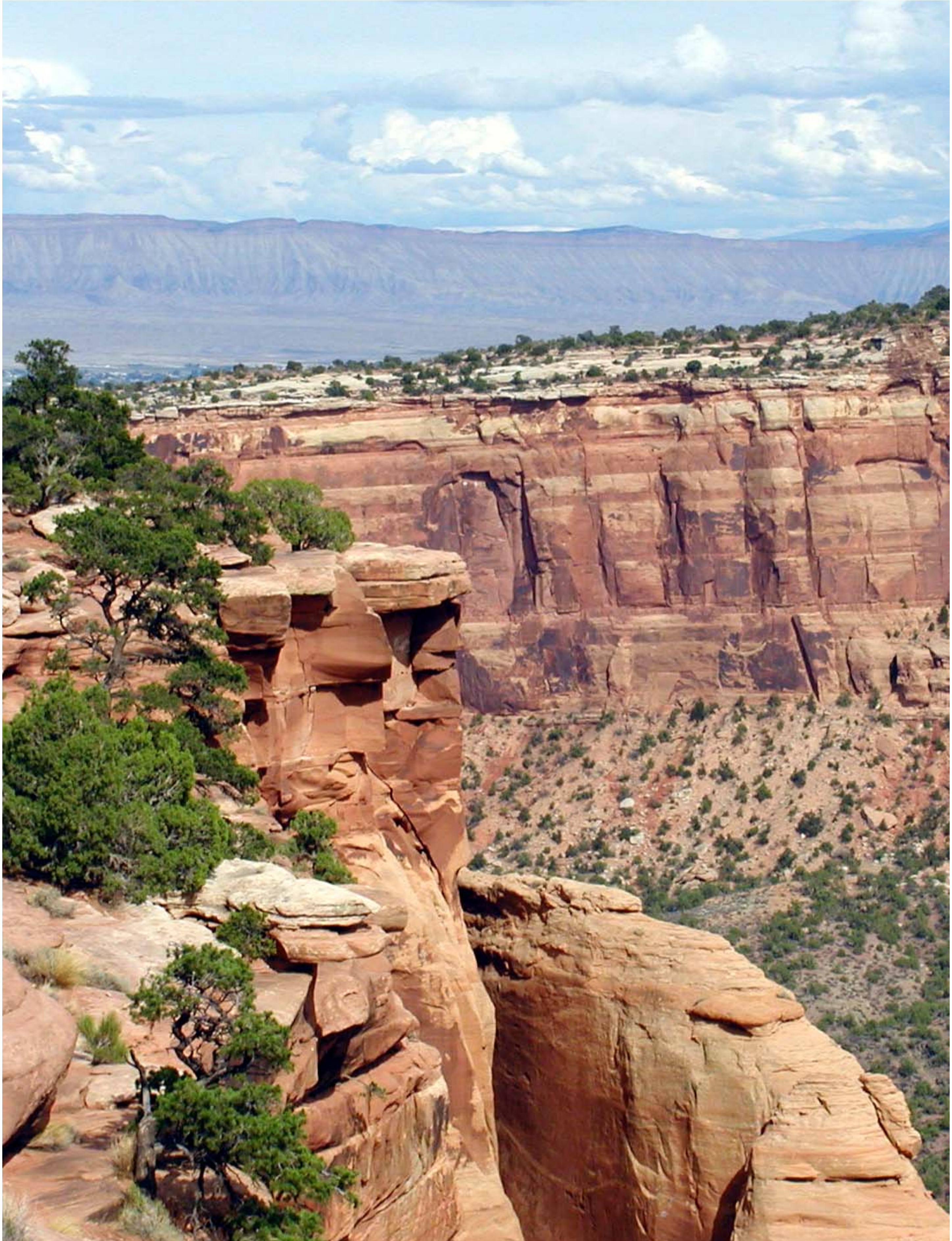
U.S. Department of the Interior
Washington, DC

NPS, April 2003

Cover: View of Independance Monument from Book Cliff, Colorado NM.

Opposite: Rock Slide along Rim Rock Drive, Colorado NM.



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Opposite: Cliff Forming Entrada Sandstone, Colorado NM.

No Thouroughfare Canyon showing valley fill sediments in center, Colorado NM.

Introduction

A geoindicators scoping meeting for Colorado National Monument was held in Fruita, Colorado, on September 9-10, 2002. Participants included staff from the National Park Service's Geologic Resources Division (GRD), Colorado National Monument, and other geologists and resource experts.

Purpose of meeting

The purpose of the meeting was threefold: (1) to identify significant geological processes and features that are part of the park's ecosystem, (2) to evaluate human influences on those processes and features, and (3) to provide recommendations for studies to support resource management decisions, geologic inventory and monitoring projects, and research to fill data gaps. The scoping meeting was designed to use the participants' expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

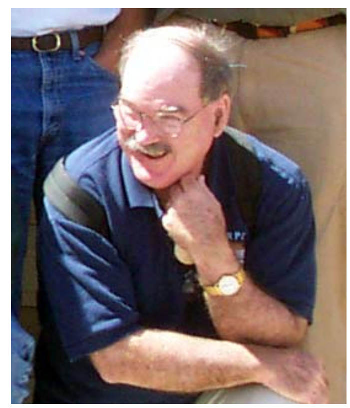
Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at Colorado National Monument may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information

An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

The health and stability of an ecosystem is evaluated during the geoindicators scoping process. The geologic resources of a park soils, caves, streams, springs, beaches, volcanoes, etc.-provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility, hillside stability, and the flow styles of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts (Appendix D).

"...Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes."



Bob Higgins, NPS Chief Geologist

Park selection

The geoindicators scoping meeting in Colorado National Monument grew out of a technical assistance request, which park managers submitted to the Geologic Resources Division. The request was fourfold: (1) to identify human/outside influences on the park's geologic resources, (2) to quantify flash floods and other geologic hazards, (3) to identify research to better understand geologic resources, and (4) to request funding for a Geoscientist-in-the-Park (GIP). Staff at GRD recognized the connection between the request and the geoindicators scoping process, so it was agreed to carry out a scoping meeting. In addition Colorado National Monument was selected for is its unique geologic resources, park setting, and human use (See Appendicies E, and F).

Colorado National Monument Geoindicators Table

Geoindicators	Importance to park ecosystem	Human influence on geology	Significance for management
AEOLIAN			
Dune formation and reactivation	1	1	1
Dust storm magnitude, duration, and frequency	1	1	1
Wind erosion	1	1	1
GROUNDWATER			
Groundwater quality	2	2	3
Groundwater level	3	U	4
SURFACE WATER			
*Stream channel morphology	5	1	5
*Stream sediment storage and load	5	1	5
*Streamflow	5	1	5
Surface water quality	1	1	3
SOILS			
Soil quality	2	1	2
Soil and sediment erosion	5	4	2
Desert surface crusts and fissures	2	5	4
TECTONICS & LANDSLIDES			
Seismicity	1	N/A	1
Slope failure	5	3	5
Surface displacement	1	N/A	1
OTHER			
Wetlands extent, structure, hydrology	4	4	3
N/A - Not Applicable 1 - LOW or no substantial influence on, or utility for 3 - MODERATELY influenced by, or has some utility for 5 - HIGHLY influenced by, or with important utility for U - Unknown; may require study to determine applicability NOTE - 2 and 4 are also rating options			
*Linked to flash floods			

The above Geoindicators table shows rankings for those geoindicators deemed (1) important to Colorado National Monument's ecosystem, (2) to have significant human influences, and (3) to be of significance for park management.

Summary of Results

During the scoping meeting, geoindicators appropriate to Colorado National Monument were addressed. Of the 27 geoindicators (Appendix A), 16 were recognized as on-going processes in Colorado National Monument.

Issues surrounding each geoindicator are identified, and have been rated by participants with respect to ecosystem importance ecosystem and human influence (Geoindicators table). Park staff rated the significance for park management. A compilation of the notes taken during the scoping session (Appendix G) and the opening session and field trip (Appendix H) are included in the appendices. These notes highlight additional information regarding geoindicators that may be useful to park managers.

Road construction may undermine the geologic integrity of slopes leading to rockslides like the one pictured above. Such slides can cause infrastructure damage and expose visitors risk.

Geoindicators with importance to park ecosystem

Groundwater level
Water is a rare resource in Colorado National Monument, wildlife and plants, including T&E species, depend upon it. Groundwater supplies seeps and springs, which are areas of high biodiversity. Locally groundwater levels are very important, for example, in Ute Canyon, where the south canyon-side gets groundwater discharge that feeds plants.

Slope failure
Slope failure includes landslides, rockfalls, and debris flows, which are an integral part of the ecosystem at Colorado National Monument. Slope failure happens continuously throughout the park, although not all rock units disintegrate at the same rate. In general, slope failure creates piles of rubble that have greater permeability and porosity than the original surfaces, which increases infiltration potential and creates "new" land surfaces upon which habitats can evolve.

Soil and sediment erosion
The process of erosion created the landforms of Colorado National Monument. It is a fundamental natural process that has been operating for millions of years, and the development of the present-day ecosystem is an outcome of the processes of erosion.

Stream channel morphology, streamflow, stream sediment storage and load
The primary reason that these three geoindicators are significant for the park's ecosystem is because of the roles they play in the formation of the park's landscape, particularly canyons. The significance of these three geoindicators is best appreciated during flash floods.

Wetlands extent, structure, and hydrology
There is a lithologic control on the wetlands in Colorado National Monument. The scarcity of wetlands increases their importance to plants and wildlife as a source of water. They also provide cooler temperatures. Greater plant and animal diversity have been identified in wetland areas, and they are sites of hanging gardens, which provide habitat for threatened and endangered species.

"Slope failure, including rockfalls, is a natural process that has been ex - acerbated by human im- pacts..."

Erosion is a fundamental and complex natural process that is strongly modified by human activities.

Geoindicators with significant human influences

Desert surface crusts and fissures
The human-caused impact on surface crusts and fissures (biological and physical crusts) has been intense in the some of the canyon areas of the park. For example, starting in the 1930s, a herd of bison (up to 60 head) grazed throughout the canyon areas and disturbed some areas of soil crusts; this practice ended in the 1980s. The herd was an attempt by John Otto to encourage visitors to come to Colorado National Monument. In addition, damage of crusts occurred in Civilian Conservation Corps (CCC) camps and along major trail corridors.

Slope failure
Slope failure, including rockfalls, is a natural process that has been exacerbated by human impacts, such as the construction of the Rim Rock Drive and by vibration from heavy vehicles (e.g., trucks, tour buses, and school buses).

Soil and sediment erosion
Erosion is a fundamental and complex natural process that is strongly modified by human activities. Human influences on soil and sediment erosion in Colorado National Monument occur on a local-scale, the primary influence being Rim Rock Drive (e.g., road cuts and increased runoff). The proliferation of social trails, which is tied to increasing visitation, also causes erosion on a local-scale (e.g., in Monument Canyon, lower Liberty Cap trail, No Thoroughfare Canyon, trail between Visitor Center and Book Cliffs View, and Alcove Trail).

Social trails like those shown below increase soil compaction and lead to accelerated rates of erosion within the monument.

Wetlands extent, structure, and hydrology
A significant human influence on wetlands in the park has been the Fruita pipeline, which leaked and created artificial habitats ideal for exotic plants. Additionally, two reservoirs were constructed to provide water to the citizens of Fruita. These are no longer in use, but future demand could cause them to be restored, which is a concern for park management. In addition, the CCC-camp members dammed the spring in Monument Canyon, and present-day trails pass through wetlands in canyon areas.

Geoindicators with management significance

Desert surface crusts and fissures
Park management recognizes that biological and physical crusts are a unique and fragile resource. An inventory of locations is needed in order for park management to plan for the proper placement of trails and for the purposes of visitor education.

Groundwater level
Groundwater level has high management significance because a decrease in groundwater level could have a direct effect on the park's seeps and springs, which are important resources. Quantifying groundwater level is important for management because this information could be used for planning and future decision-making as it relates to development outside of the park's boundary (e.g., in Glade Park).

Groundwater quality
Changes in groundwater chemistry could affect organisms at seeps and springs. Although the risk of contamination is probably not high at present, this could change in the next 50 to 100 years. As Glade Park grows, the chances of groundwater contamination will increase. The risk also depends on the kinds of changes that may take place in land use and water use in the recharge area, as some changes will pose more serious threats than others.

Slope failure

Slope failure happens continuously throughout the park and is a constant maintenance issue along Rim Rock Drive. Rim Rock Drive is an important park resource, which facilitates public enjoyment and the ability to view the park. Slope failure is a concern for park management, particularly with respect to potential road failure. Rockfalls are also a concern of park managers for reasons of visitor safety, especially along Rim Rock Drive and at overlooks.

Stream channel morphology, Streamflow, Stream sediment storage and load

These three geoindicators are active components of flash floods, which are of primary management significance and affect all park divisions/units (e.g., maintenance, interpretation, resource management). Flash floods are the principal agent that form and modify the canyons, as well as being a concern for homeowners. Park staff has a role to fill as public educators regarding flash floods. Park managers recognize the significance of flash floods to the park's ecosystem. They also recognize the importance of educating homebuilders and homeowners about the long history of flash flooding in the area and making responsible decisions with respect to the location of homes.

Wetlands

If more water is needed in Fruita in the future, management has concerns that the old water line would be reactivated. Intense damage to park resources, associated with required reconstruction activities, would accompany reactivation of the water line.

Above: Seeps and springs create unique ecosystems in the arid environment of Colorado National Mounment

Below: Ephemeral streams act as conduits for flashfloods during frequent summer thunderstorms.

Summary of Recommendations

The following summary of recommendations lists ideas that were discussed during the September 9-10, 2002 scoping meeting held in Colorado National Monument.

The summary includes recommendations for inventory, monitoring, and research studies, as well as recommendations for public education and park planning. Recommendations are not listed in any order of priority.

An inventory of areas along the Rim Rock Drive and overlooks with high potential for slope failure would have value for inventory, monitoring, and planning.

Recommendations for inventory and monitoring

1. Identify areas with high potential for slope failure

An inventory of areas along the Rim Rock Drive and overlooks with high potential for slope failure would have value for inventory, monitoring, and planning. High potential areas could be identified with GPS and incorporated into the park's GIS. Such an inventory would enable park managers to focus on particular areas, rather than 23 miles of road.

Rangers who regularly drive on the road could assist with the process by identifying cracks in the asphalt and entering those data into a GPS unit, which could be incorporated into GIS. A yearly monitoring day could be set aside to revisit and evaluate these areas.

Another simple monitoring technique is to place stakes in landslide material along the road to detect movement/creep. A survey of these areas could be performed once every two years. This is a low-cost project that would provide valuable information to park managers.

Once inventories of areas with high potential for slope failure are incorporated into the park's GIS, park managers will have a valuable planning tool that could be used for (1) locating "warning" signs, and (2) coming up with options for rerouting the road, if/when it fails.

2. Gather scientific information on seismicity and wind-blown sediments

Although seismicity and wind-blown sediments are of low management significance, having a seismic station and wind-blown sediment monitoring station in the park would have scientific value and encourage collaboration between the park and the local academic community. Mesa State College would be interested in having one seismic station located in Colorado National Monument, possibly in the maintenance or housing area. Three stations are needed to get accurate local information. Staff at Mesa State College would monitor and maintain the station.

Contact

➤ Verner Johnson, vjohnson@mesastate.edu, Mesa State Geology Program

Mesa State College needs a used computer to complete the seismic station. The NPS Natural Resource Program Center may be able to donate a computer.

Contact

➤ Bob Higgins, GRD, Bob_Higgins@nps.gov, 303-969-2018.

In addition, Mesa State College's Geology Program would be interested in having a monitoring station for wind-blown sediment in Colorado National Monument. They would need a collection permit and a sheltered spot to place the traps, which they would monitor once per year.

Contact

➤ Mesa State College's Geology Program, geology@mesastate.edu, 970-248-1020

3. Use geology to identify paleontological and archeological sites within the park
Park managers expressed the desire to use geology as a tool for identifying other natural and cultural resources. Participants identified some contacts for future studies.

Paleontological Contacts
➤ John Foster, Museum of Western Colorado, jfoster@westcomuseum.org, 970-858-7282

➤ Greg McDonald, Geologic Resources Division, Greg_McDonald@nps.gov, 303-969-2821

Possible Archeology Contact
➤ Mesa Verde National Park

4. Gather baseline data on flash floods
Repeat photography may be an option for gathering baseline information on flash floods. Since floods will leave debris, photographing during the event may not be necessary. A volunteer could be trained to take photos after each flooding event, which occur approximately twice per year, typically during July and August. The NPS Geoscientist-in-the-Parks (GIP) program may be able to provide funding for camera equipment.

Contact
➤ Judy Geniac, GIP Program Manager, Geologic Resources Division, Judy_Geniac@nps.gov, 303-969-2015

Another possibility would be to install cameras in selected drainages (where homes are in the most jeopardy) to photo document flooding.

Contact
➤ Paul Vonguerard, 970-858-3617, pbvongue@mailscogjn.cr.usgs.gov

5. Include inventory of soil crusts in mapping of vegetation
Biological and physical soil crusts are a unique resource in Colorado National Monument and should be preserved because of their potential to protect underlying fine material from wind erosion; fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

It is recommended that locations of these crusts be identified and incorporated into the park's GIS in order to protect and preserve soil crusts. An inventory of crusts would enable park managers to plan the placement of trails accordingly and educate visitors appropriately. Locations of these crusts should also be linked to the Fire Management Plan, since the greatest amount of crusts occur where there is the greatest amount of piñon and juniper. Future plans for operations related to prescribed burns or mechanical fuel reduction could have a negative impact on soil crusts.

Contact
➤ Eric Aiello, Eric_Aiello@nps.gov, 970-242-7385

➤ Jayne Belnap, U.S. Geological Survey in Moab, 435-719-2333, jayne_belnap@usgs.gov

6. Identify baseline level of groundwater and periodically monitor
Baseline data are needed in order to detect groundwater depletion caused by increased development in areas bordering Colorado National Monument, such as Glade Park. Groundwater is a valuable resource for the park's seeps and springs, and increased extraction could have a negative effect on these valuable resources, as well as on the organisms that rely on them.

Potential sources of data
➤ Rocky Mountain Drilling, Glade Park, 970-434-8554

➤ Dennis Karns, Ute Construction, 970-243-2469

References

Lohman, S.W., 1965, Geology and artesian water supply of the Grand Junction area, Colorado: U.S. Geological Survey Professional Paper 451, 149p.

Lohman, S.W., 1963, Geologic map of the Grand Junction area, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-404, scale 1:31,680.

Upon determining a baseline of groundwater level, it is recommended that park managers perform periodic monitoring. At a minimum a network of wells should be monitored at least annually but preferably quarterly or more often. Since the park does not have a monitoring well, one option would be for park managers to attain permission from homeowners in Glade Park to monitor water level in private wells. The U.S. Geological Survey has capabilities to advise or participate in this activity.

Another important issue would be to identify the groundwater recharge area for Colorado National Monument. Determining the rate of groundwater withdrawal in the recharge area will be an important step in understanding outside development on groundwater resources of Colorado National Monument.

Contact

➤ Paul Vonguerard, 970-858-3617, pbvongue@mailscogjn.cr.usgs.gov

7. Identify baseline for groundwater quality and periodically monitor

This baseline should include water chemistry at seeps and springs, and at selected wells in Glade Park. Changes in land use and water may pose threats to groundwater quality.

8. Inventory wetlands

Park managers in Colorado National Monument have some information about wetlands in the park because of the survey of tamarisk that was conducted. To date, two wetland areas have been identified (e.g., upper Ute Canyon and upper No Thoroughfare Canyon), with a total of about 20 acres. Wetlands in the park will be inventoried through the vegetation mapping program using GIS. Locations of all wetlands need to be mapped, ground truthed, and digitized.

References

Cowardian, L.M, Carter, V., Golet, F.C., and LaRoe,E.T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Department of the Interior, Fish and Wildlife Service, FWS/OBS-79/31.

9. Work with soil scientist to better understand soil quality

Upon review of this scoping report, it was the opinion of a soil science expert that some of the observations made during the scoping session regarding soil quality were incorrect (see Appendix G). It is recommended that the soil quality of Colorado National Monument be revisited, and correction and clarification be made prior to making management decisions.

Contact

➤ Pete Biggam, 303-987-6948, pete_biggam@nps.gov

Recommendations for research

1. Create a flash flood model

Create a flash flood model and run for each drainage in Colorado National Monument. This could be a GIP project. Park managers could work with local professors at Mesa State College (geomorphology, hydrology, and GIS). In order to verify the model, data collection is needed that measures peak flow drainages in Colorado National Monument. Installation of crest-stage gages and the rating of stream channels using the step-backwater method would provide the basic data needed to support flash -flood models. The U.S. Geological Survey may be able to participate.

Contact

➤ Judy Geniac, GIP Program Manager, Geologic Resources Division, Judy_Geniac@nps.gov, 303-969-2015

➤ Paul Vonguerard, 970-858-3617, pbvongue@mailscogjn.cr.usgs.gov

2. Consider integrated research proposal to examine valley fill

This proposal could provide valuable information to park managers regarding rates of erosion, past climate change, and sources of sediment (Appendix I).

3. Put seeps and springs inventory into digital format

Currently park staff has hand-drawn maps of seeps and springs on 7.5-minute topographic maps. These data are assumed to have been collected at the same time as a vegetation study in 1984. Eric Aiello, park Cartographic Aid and student at Mesa State College, has been making a 3D model of the park. He has acquired software to do some analysis on the watersheds in Colorado National Monument. Participants thought that this project is a prime candidate for Geoscientist-in-the-Park (GIP) funding and encourage park managers to submit a GIP proposal.

Contact

➤ Judy Geniac, GIP Program Manager, Geologic Resources Division, Judy_Geniac@nps.gov, 303-969-2015.

Recommendation for public education

Develop a plan for educating the public about flash floods

It is recommended that park staff collaborate with the U.S. Geological Survey, Colorado Geological Survey, and/or local geologists to develop a long-term plan for educating the public about flash floods. The plan could be modeled after the fire community's efforts, which has been successful. A possible "kick-off" event may be to host a public field trip that highlights the long history of flash floods in the area. The trip could commemorate the 25th anniversary of the large flash flood that occurred in September 1978. The local community, including County Commissioners, should be invited.

Recommendation for park planning

Develop a long-term plan for road failure

The park has a short-term plan for closure of Rim Rock Drive but not a long-term plan, if large sections of the road are destroyed. Recent history shows that a road closure is a reality, e.g., Rim Rock Drive was closed for one year when the area between the two tunnels was washed out. A long-term plan for road closure, rerouting, maintenance, etc. needs to be part of General Management Plan (GMP). It is recommended that park staff work with geologists, engineers, and the Federal Highway Administration to plan alternatives. The plan for rerouting the road should take into consideration the geologic strata, location of facilities, and wilderness. In addition, fire plays a role in (and could indirectly trigger) landslides; therefore, slope failure should be part of the Fire Management Plan. The potential to mitigate landslides with smaller, prescribed burns should be considered.

Meeting Participants included, Back row (left to right): Palma Wilson, Ron Young, Don Baars, Suzy Stutzman, Tom Wylie, Sid Covington, Dave Price. Front Row (left to right): Bill Hood, Katie KellerLynn, Paul Vonguerard, Bob Higgins

List of Participants

Colorado National Monument

Eric Aiello, Cartographic Aid
Don Baars, Geologist/Volunteer-in-the-Park
Bill Hood, Geoscientist-in-the-Park/Volunteer-in-the-Park
Pete Larson, Park Ranger
Dave Price, Chief of Resource Management
Ron Young, Supervisory Park Ranger
Palma Wilson, Superintendent

National Park Service

Pete Biggam, Natural Resources Information Division
(review of soil quality geoindicator only)
Sid Covington, Geologic Resources Division
Bob Higgins, Geologic Resources Division
Greg McDonald, Geologic Resources Division
Suzy Stutzman, Intermountain Region Support Office

Other Participants

Katie KellerLynn, Geologist/NPS Contractor
Paul Vonguerard, Subdistrict Chief, U.S. Geological Survey Water Resource Division
Tom Wylie, Natural Resource Consultant, General Management Plan Team Member

Appendices

Appendix A: Descriptions of 27 Geoindicators
Appendix B: Human Influences
Appendix C: Introducing Geoindicators
Appendix D: Species Don't Stand Alone—Geology's Role in Ecosystems
Appendix E: Park Setting
Appendix F: Park Geological Setting
Appendix G: Compilation of Notes taken during the Scoping Session
Appendix H: Compilation of Notes taken during Opening Session and Field Trip
Appendix I: Proposal for Study of Valley Fill

Appendix A:
Description of 27 Geoindicators

Geoindicators have been developed as tools to assist in integrated assessments of ecosystems, as well as for environmental reporting.

As descriptors of common earth processes that operate in a variety of settings, geoindicators represent collectively a new kind of landscape metric, one that concentrates on the non-living components of the lithosphere, pedosphere, and hydrosphere, and their interactions with the atmosphere and biosphere (including humans).

The Geoindicator Checklist:

Geoindicators are available in the form of a checklist that identifies 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

The descriptions of geoindicators that follow were adapted from the geoindicators checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Each geoindicator includes a brief description, reasons for its significance to an ecosystem, and examples of human influences from national park settings (when available). The National Park Service uses these descriptions to facilitate discussion during scoping meetings in national parks. The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. For each scoping meeting, geoindicators are selected from the list of 27, as appropriate to the terrain and environmental issues under consideration.

Coral chemistry and growth patterns

Brief Description:
Corals can be used to monitor environmental changes in the oceans and nearby coastal zone. The health, diversity, and extent of corals, and the geochemical makeup of their skeletons, record a variety of changes in the ocean surface water. These include temperature, salinity, fertility, insolation, precipitation, winds, sea levels, storm incidence, river runoff, and human inputs. Corals in coastal waters are susceptible to rapid changes in salinity and suspended matter concentrations and may be valuable indicators of the marine dispersion of agricultural, urban, mining, and industrial pollutants through river systems, as well as the history of contamination from coastal settlements.

Significance:
The combination of abundant geochemical tracers, sub annual time resolution, near perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives.

Human influence:
Corals respond to both natural changes in the marine environment and to anthropogenic pollution.

Desert surface crusts and fissures

Brief Description:
The appearance or disappearance of thin (mm to cm) surface crusts in playas and depressions in arid and semi-arid regions may indicate changes in aridity. The formation of persistent deep, polygonal cracks in the mud and silt floors of closed basins and depressions may indicate the onset of aridification or severe drought. Surfaces may contain other desiccation features such as sedimentary dikes, evaporite deposits (especially gypsum and halite), adhesion ripples, and large salt polygons.

Physical soil crusts (thin layer with reduced porosity and increases density at the surface of the soil) and biological soil crusts (a living community of lichen, cyanobacteria, algae, and moss growing on the soil surface and binding it together) are also significant indicators of the state of an ecosystem. Recovery of biological crusts may take decades to hundreds of years. The amount and extent of degration to soil crusts are excellent indicators of physical disturbance.

Significance:
Desert surface crusts are important because they protect the underlying fine material from wind erosion. Physical and biological crusts; in Canyonlands and Arches national parks, for instance; generally help to control wind erosion. Biological crusts fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

Human Influences:
The formation of surface crusts is related primarily to natural causes, but hydrological regimes that affect crust formation and persistence may be altered by human activities, such as river diversion and groundwater extraction. Both physical and biological crusts can be affected by physical disturbances caused by wheeled or tracked vehicles, livestock hooves, and hiking and cycling. The impact is determined by the severity, frequency, and timing of the disturbance and by the size of the disturbed area.

In Arches National Park, grazing practices have impacted physical and biological crusts. Seventy-five percent of the park was grazed until 1974, and cow trespass still occurs. Soil and nutrient cycles have not recovered from this past practice (2002). Trampling by visitors at North and South Window Arch, to "get the perfect picture" or to short-cut to the parking lot, has damaged soil crusts in the area. On the boundary of Arches and Canyonlands national parks, the use of seismic "thumper" trucks during oil and gas exploration created 160 miles of roads and 110 miles of ATV tracks—all of which damaged soil crusts in the area.

Dune formation and reactivation

Brief Description:
Dunes and sand sheets develop under a range of climatic and environmental controls, including wind speed and direction, and moisture and sediment availability. In the case of coastal dunes, sea-level change and beach and nearshore conditions are important factors. Organized dune systems and sheets in continental environments form from sediment transported or remobilized by wind action. New generations of dunes may form from sediment remobilized by climatic change and/or human disturbances.

Sand movement is inhibited by moisture and vegetation cover, so that dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology or position may indicate variations in aridity (drought cycles), wind velocity and direction [see wind erosion], or disturbance by humans.

Significance:
Moving dunes may engulf houses, fields, settlements, and transportation corridors. Active dunes in sub-humid to semi-arid regions decrease arable land for grazing and agriculture. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing, and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

Human Influence:
Widespread changes can be induced by human disturbance, such as alteration of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

Sleeping Bear Dunes National Seashore has a number of prominent dunes (300-400 ft high): Sleeping Bear Dune, Empire Dunes, Pyramid Dunes, Michigan Overlook, and the Dune Climb. Most of these dunes are perched dunes and consist of a relatively thin blanket of sand that has been blown to the top of thick glacial deposits. Foot traffic and social trails have highly modified the Dune Climb and Michigan Overlook, very popular visitor sites. The Dune Climb, once a perched dune, has evolved and migrated off the plateau onto the adjacent lowland.

In Cape Cod National Seashore, migration of the dunes has caused alarm since the 19th century. Dunes have migrated into Pilgrim Lake, over homes in Provincetown, and onto roads. In the 1980s, mitigation efforts were seen as a top priority, and funding was spent on efforts such as pouring asphalt onto the dunes and revegetating the dunes.

Dust storm magnitude, duration, and frequency

Brief Description:
The frequency, duration, and magnitude (intensity) of dust storms are gauges of the transport of dust and other fine sediments in arid and semi-arid regions [see wind erosion]. Desert winds carry more fine sediment than any other geological agent. An increased flux of dust has been correlated with periods of drier and/or windier climates in arid regions, historically and from proxy records in ocean and ice cores.

Significance:
Local, regional, and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and

topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 m, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

Human Influence:
Dust storms are natural events, but the amount of sediment available for transport may be related to surface disturbances such as overgrazing, ploughing, or removal of vegetation. Identified as single events on the scale of days in Arches and Canyonlands national parks, dust storms cause hazardous travel conditions. In addition, dust storms transport contaminated sediment from the Atlas Mine tailings pile (outside park boundary) into the employee housing area in Arches National Park.

Frozen ground activity

Brief Description:
In permafrost and other cryogenic (periglacial) areas and in temperate regions where there is extensive seasonal freezing and thawing of soils, a wide range of processes lead to a variety of surface expressions, many of which have profound effects on human structures and settlements, as well as on ecosystems.

These sensitive periglacial features are found around glaciers, in high mountains (even at low-latitudes) and throughout polar regions. The development (aggradation) or degradation of permafrost is a sensitive and early indicator of climate change [see subsurface temperature regime].

Important geological parameters related to permafrost regions include:

1. Thickness of the active layer, the zone of annual freezing and thawing above permafrost, determines not only the overall strength of the ground but also many of the physical and biological processes that take place in periglacial terrains. Soil moisture and temperature, lithology, and landscape morphology exercise important controls on active layer thickness. Soil moisture and temperature depend largely on climatic factors, so that if the mean annual air temperature rises several degrees Celsius, the thickness of the active layer may change over time periods of years to decades.

2. Frost heaving is a basic physical process associated both with near surface winter freezing and with deeper permafrost aggradation. Frost heaving can displace buildings, roads, pipelines, drainage systems, and other structures. Many frozen soils have a much greater water content than their dry equivalents and undergo a local 10-20% expansion in soil volume during freezing. The frost heave process and the consequences of thawing are of great importance in the development of many of the unique features of cold terrains, including perennial hummocks and seasonal mounds, patterned ground, palsas, and pingos.

3. Frost cracks are steep fractures formed by thermal contraction in rock or frozen ground with substantial ice content. They commonly intersect to create polygonal patterns, which may lead to the formation of wedges of ice and surficial material. The frequency of cracking is linked to the intensity of winter cold. Where climate is warming, ice-wedge casts replace ice wedges over periods of decades.

4. Icings are sheetlike masses of layered ice formed on the ground surface, or on river or lake ice, by freezing successive flows of water that may seep from the ground, flow from a spring or emerge from below river or lake ice through fractures. The intensity of icings in the southern portions of the permafrost zone may change annually, increasing with colder winters and lower snow cover combined with autumnal precipitation. Further north, icings increase in size but decrease in number when the climate cools, and vice-versa when it warms.

5. Thermoerosion refers to erosion by water combined with its thermal effect on frozen ground. Small channels can develop into gullies up to several kilometers in length, growing at rates of 10-20 m/yr, and in sandy deposits, as fast as 1 m/hr. The main climatic factors controlling the intensity of thermoerosion are snow-melt regime and summer precipitation.

6. Thermokarst refers to a range of features formed in areas of low relief when permafrost with excess ice thaws. These are unevenly distributed and include hummocks and mounds, water-filled depressions, “drunken” forests, mud flows on sloping ground, new fens, and other forms of thaw settlement that account for many of the geotechnical and engineering problems encountered in periglacial landscapes. Even where repeated ground freezing takes place, thermokarst features, once formed, are likely to persist.

7. Permafrost terrains are characterized by a wide range of slow downslope movements involving creep, such as rock glaciers and gelifluction, and by more rapid landslides and snow avalanches [see slope failure].

Significance:
Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further (global) climate change by the release of carbon and other greenhouse gases during thawing. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

Human Influence:
The freezing and thawing of soils and surficial materials and the consequent ground changes are natural processes controlled by climatic conditions, and can be modified by human actions in and around settlements and engineering works.

Frozen ground activity (frost heave and gelifluction) is a major geologic process active in Rocky Mountain National

Park. Patterned ground (e.g., stone polygons and stone stripe features) occurs in high alpine areas. These features are thought to form from frost heave and frost cracking and are extremely sensitive to human disturbance. Visitors have access to patterned ground along the "Tundra World Nature Trail." There is limited parking in this area, which may cut down on the number of visitors who access the patterned ground. Furthermore, visitors are asked to fan out when walking across these surfaces to minimize disturbance of these features.

Glacier fluctuations

Brief Description:
Changes in glacier movement, length, and volume can exert profound effects on the surrounding environment, for example through sudden melting which can generate catastrophic floods, or surges that trigger rapid advances. Twice in the last hundred years the Muldrow Glacier in Denali National Park and Preserve has "surged" flowing over lower stagnant ice and making a jumble of broken ice-blocks. Movement along the fault may trigger a surge.

Standard parameters include mass balance and the glacier length, which determines the position of the terminus. The location of the terminus and lateral margins of ice exerts a powerful influence on nearby physical and biological processes. Through a combination of specific balance, cumulative specific balance, accumulation area ratio, and equilibrium-line altitude, mass balance reflects the annual difference between net gains (accumulation) and losses (ablation). It may also be important to track changes in the discharge of water from the glacier as indicators of glacier hydrology. Abrupt changes may warn of impending acceleration in melting, cavitation, or destructive flooding.

Significance:
Glaciers are highly sensitive, natural, large-scale, representative indicators of the energy balance at Earth's surface in polar regions and high altitudes. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The advance and retreat of mountain glaciers creates hazards to nearby human structures and communities through avalanches, slope failure, catastrophic outburst floods from ice and moraine-dammed lakes. Notwithstanding local glacier advances, the length of mountain glaciers and their ice volume have decreased throughout the world during the past century or two, providing strong evidence for (global) climate warming, though there may also be local correlations with decreasing precipitation.

Human Influence:
Glaciers grow or diminish in response to natural climatic fluctuations. They record annual and long-term changes and are practically undisturbed by direct human actions.

Groundwater quality

Brief Description:
The chemistry (quality) of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes. The relatively slow movement of water through the ground means that residence times in groundwaters are generally orders of magnitude longer than in surface waters.

As in the case of surface water quality, it is difficult to simplify to a few parameters. However, in the context of geoindicators, a selection has been made of a few important first-order and second-order parameters that can be used in most circumstances to assess significant processes or trends at a time-scale of 50-100 years. The following first order indicators (in bold) of change are proposed, in association with a number of processes and problems, and supported by a number of second order parameters:

1. Salinity: Cl, SEC (specific electrical conductance), SO_4, Br, TDS (total dissolved solids), Mg/Ca, d18O, d2H, F
2. Acidity & Redox Status: pH, HCO_3, Eh, DO, Fe, As
3. Radioactivity: 3H, 36Cl, 222Rn
4. Agricultural Pollution: NO_3, SO_4, DOC (dissolved organic carbon), K/Na, P, pesticides and herbicides
5. Mining Pollution: SO_4, pH, Fe, As, other metals, F, Sr
6. Urban Pollution: Cl, HCO_3, DOC, B, hydrocarbons, organic solvents

During development and use of an aquifer, changes may occur in the natural baseline chemistry that may be beneficial or detrimental to health (e.g., increase in F, As); these should be included in monitoring programs. The quality of shallow groundwater may also be affected by landslides, fires, and other surface processes that increase or decrease infiltration or that expose or blanket rock and soil surfaces which interact with downward-moving surface water.

Significance:
Groundwater is important for human consumption on a global scale, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.

Human Influence:
Changes in natural baseline conditions may occur over the timescales of interest, and may be measured at an individual borehole or spring. Superimposed on these, however, are the greater impacts of human activities.

Practices in parks may influence groundwater quality. Approximately one mile south of the Canyonlands Visitor

Center (Needles District) is an abandoned landfill that operated from 1966 to 1987. Hazardous substances including paint thinners, pesticides, human wastes, and oils were disposed at this landfill during operation. The soils consist of alluvial and eolian deposits (loose sandy material) of high permeability 10 to 20 feet deep; thus the potential for groundwater contamination exists in the area. The closest domestic well is 3,000 feet north of the landfill.

Groundwater chemistry in the unsaturated zone

Brief Description:
Water moves downwards through porous soils and sediments and, under favorable conditions, may preserve a record of weathering processes, climatic variations (in the Cl or isotopic signature), or human activities such as agriculture (NO_3) and acidification (H^+). This indicator may be considered as the output from the soil zone and may reflect the properties or change in properties of soils. Rates of downward movement are typically 0.1 to 1.0 m/yr, and a record of individual events (resolution 1-20+ years) may be preserved over a scale of decades or centuries [see groundwater quality; soil quality]. In contrast, records collected over periods of years are needed to establish trends from the monitoring of rivers and streams or groundwater discharge [see groundwater quality; surface water quality]. The unsaturated zone is also an important buffering zone for attenuation of acidity, metal content, and some other harmful substances.

Significance:
Changes in recharge rates have a direct relationship to water resource availability. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

Human Influence:
Depending on land use, the unsaturated zone beneath a site may record the effects of human activities such as agriculture and industrial activity, or regional problems such as acidic deposition.

Groundwater level

Brief Description:
Groundwater is replenished from precipitation and from surface water, but the rate of abstraction (withdrawal by humans) may exceed the rate of natural recharge, leading to reduction of the resource. Some aquifers, especially in arid and semi-arid regions, contain paleowaters stored from earlier periods of wetter climate; the reduction of these reserves is comparable to "mining." In alluvial plains, reduction in streamflow reduces the rate of natural recharge to aquifers. Measurement on a regular basis of water levels in wells and boreholes or of spring discharge provides the simplest indicator of changes in groundwater resources. However, springs may be perennial, intermittent, or periodic, and their discharge may depend on changes in climate, tides, and local underground conditions such as changes in rock stresses.

Significance:
The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge: groundwater mining is a terminal condition.

Human Influence:
There are natural changes in groundwater levels because of climate change (drought, pluvial episodes), but the main changes are due to human abstraction. In many places artificial recharge of aquifers is accomplished deliberately by pumping or as an indirect result of irrigation.

The majority of available fresh water in Cape Cod National Seashore is groundwater. On the lower Cape, all groundwater has local precipitation as its source. The groundwater resource directly supports most of the lower Cape's surface water—ponds, streams, and fresh water wetlands. The human populations of the lower Cape are also entirely dependent on the groundwater for private and municipal water supply.

There are three primary groundwater withdrawal concerns facing Cape Cod National Seashore as development continues and the demand for new private and public water wells increases. First, excessive groundwater withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the groundwater volume may be depleted to a point where salt water intrudes and contaminates the fresh groundwater.

Karst activity

Brief Description:
Karst is a type of landscape found on carbonate rocks (limestone, dolomite, marble) or evaporites (gypsum, anhydrite, rock salt) and is typified by a wide range of closed surface depressions, well-developed underground drainage system, and a paucity of surface streams. The highly varied interactions among chemical, physical, and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation, and ground subsidence. Diagnostic features such as sinkholes (dolines), sinking streams, caves, and large springs are the result of the solutional action of circulating groundwater, which may exit to entrenched effluent streams. Most of this underground water moves by laminar flow within narrow fissures, which may become enlarged above, at, or below the water table to form subsurface caves, in which the flow may become turbulent. Caves contain a variety of dissolution features, sediments, and speleothems (deposits with various forms and mineralogy, chiefly calcite), all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst. Karst can be either a sink

or a source of CO_2, for the karst process is part of the global carbon cycle in which carbon is exchanged between the atmosphere, surface and underground water and carbonate minerals. Dissolution of carbonates, which is enhanced by the presence of acids in water, ties up carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3^-. Deposition of dissolved carbonate minerals is accompanied—and usually triggered—by release of some of the carbon as CO_2. In many karst locations, CO_2 emission is associated with the deposition of calcareous sinter (tufa, travertine) at the outlet of cold or warm springs.

Though most abundant in humid regions, karst can also be found in arid terrains where H_2S in groundwater, rising from reducing zones at depth, oxidizes to produce sulphuric acid, which can form large caves, such as the Carlsbad Caverns of New Mexico. Similar processes also operate in humid regions but tend to be masked by the CO_2 reaction. Sulphates and rock salt are rarely exposed in humid climates. They are susceptible to rapid dissolution during periodic rains where they are at the surface in drier terrains.

Significance:
Karst systems are sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, instability of overlying soils, and difficulty in designing effective monitoring systems around waste facilities. Instability of karst surfaces causes damage to roads, buildings, and other structures. Radon levels in karst groundwater tend to be high in some regions, and underground solution conduits can distribute radon unevenly throughout a particular area.

Human Influence:
Natural karst processes can be influenced by human activities such as land-use modification (e.g., deforestation), waste disposal, and opening or blocking of cave entrances, all of which can substantially affect sedimentation, speleothem deposition, and groundwater quality over the short term. Although most sinkhole collapse is triggered by high discharge of underground streams, lowering of water tables by overpumping in areas underlain by thick soils or weak rocks can induce ground failure and collapse into subsurface voids.

Lake levels and salinity

Brief Description:
Lakes are dynamic systems that are sensitive to local climate and to land-use changes in the surrounding landscape [see shoreline position]. Some lakes receive their water mainly from precipitation, some are dominated by drainage runoff, and others are controlled by groundwater systems. On a time scale ranging from days to millennia, the areal extent and depth of water in lakes are indicators of changes in climatic parameters such as precipitation, radiation, temperature, and wind speed. Lake level fluctuations vary with the water balance of the lake and its catchment, and may, in certain cases, reflect changes in shallow groundwater resources.

Especially useful as climatic indicators are lakes without outlets (endorheic). In arid and semi-arid areas, the levels and areas of lakes with outflows are also highly sensitive to weather. Where not directly affected by human actions, lake level fluctuations are excellent indicators of drought conditions. Ephemerally- or seasonally-flooded lake basins (playas) are dynamic landforms, the physical character and chemical properties of which reflect local hydrologic changes, and which react sensitively to short-term climate changes (e.g., rate of evaporation). Fluctuations in lake water salinity also provide an indication of changes in conditions at the surface (climate, inflow/outflow relations) and in shallow groundwater [see sediment sequence and composition; surface water quality].

Significance:
The history of fluctuations in lake levels provides a detailed record of climate changes on a scale of a decade to a million years. Lakes can also be valuable indicators of near surface groundwater conditions.

Human Influences:
Lake levels can be influenced by human-induced climate change, and by engineering works, such as dams and channels. Less drastic actions can also influence lake levels, for example, North Bar Lake in Sleeping Bear Dunes National Seashore, is an embayment lake that is being "loved to death." Historically, the lake was directly connected to Lake Michigan by an outlet channel. Heavy foot traffic has removed natural vegetation and destabilized the dunes near the lake. Increased sand transport from the dunes has filled in the outlet channel closing off the embayment lake, and, as a result, the embayment lake has lost its natural lake level fluctuation.

Relative sea level

Brief Description:
The position and height of sea relative to the land (relative sea level - RSL) determines the location of the shoreline [see shoreline position]. Though global fluctuations in sea level may result from the growth and melting of continental glaciers, and large-scale changes in the configuration of continental margins and ocean floors, there are many regional processes that result in rise or fall of RSL that affect one coastline and not another. These include: thermal expansion of ocean waters, changes in meltwater load, crustal rebound from glaciation, uplift or subsidence in coastal areas related to various tectonic processes (e.g., seismic disturbance and volcanic action), fluid withdrawal, and sediment deposition and compaction. RSL variations may also result from geodetic changes such as fluctuations in the angular velocity of Earth or polar drift.

Significance:
Changes in RSL may alter the position and morphology of

coastlines, causing coastal flooding, waterlogging of soils, and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt water intrusion into aquifers, leading to salinization of groundwater. Coastal ecosystems are bound to be affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island states are particularly susceptible to sea-level rise.

Human Influences:
Human actions including drainage of wetlands, withdrawal of groundwater (which eventually flows to the sea), and deforestation (which reduces terrestrial water storage capacity) may contribute to global rise in sea level. Human-induced climate change is also of obvious importance. Large engineering works, such as river channeling or dam construction, that influence sediment delivery and deposition in deltaic areas may cause local changes.

A big question in Cape Cod National Seashore is whether the marshes can keep up with sea-level rise. Cape Cod's fresh groundwater rests on seawater and necessarily rises along with sea level; therefore, the diked Pamet marsh, for example, continues to rise along with groundwater levels, but in a way that is very different from the way salt marshes normally grow. Salt marshes typically keep pace with sea-level-rise largely through the accumulation of inorganic sediment, i.e., sand, silt, and clay. The diked upper Pamet has been denied this sediment supply for over 100 years. In the meantime, any accretion has been through the production of organic matter.

Similarly, the engineering of the Mississippi River over the past 200 years has cut off sediment from nourishing and accreting the marshes at Jean Lafitte National Historical Park and Preserve (New Orleans, Louisiana), such that as the marshes subside, no new sediment is available to maintain marsh elevation.

Sediment sequence and composition

Brief Description:
Lakes, wetlands, streams (and overbanks), estuaries, reservoirs, fjords, shallow coastal seas, and other bodies of marine or fresh water commonly accumulate deposits derived from bedrocks, soils, and organic remains within the drainage basin, though fine particles can also be blown in by winds from distant natural, urban, and industrial sources. These aquatic deposits may preserve a record of past or ongoing environmental processes and components, both natural and human-induced, including soil erosion [see soil and sediment erosion; wetlands extent, structure, and hydrology], air-transported particulates [see dust storm magnitude, duration, and frequency], solute transport, and landsliding [see slope failure]. Some of these bodies of water are dynamic and sensitive systems whose sedimentary deposits preserve in their chemical, physical, and biological composition a chronologically ordered and resolvable record of physical and chemical changes through their mineralogy, structure, and geochemistry [see surface water quality]. Of particular value in determining long-term data on water chemistry are the remains of aquatic organisms, which can be correlated with various environmental parameters. In addition, fossil pollen, spores, and seeds reflect past terrestrial and aquatic vegetation. Sediment deposits can, thus, provide an indication of the degree and nature of impact of past events on the system, and a baseline for comparison with contemporary environmental change. Some lakes (and reservoirs) are open systems characterized by relatively stable shorelines and a limited residence time for solutes; others are closed (endorheic) and/or ephemeral (playas).

Significance:
The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

Human Influence:
Sediment deposition is a natural process that can be strongly influenced by human activities (e.g., land clearing, agriculture, deforestation, acidification, eutrophication, industrial pollution) within the drainage basin or sediment catchment.

George Washington Birthplace National Monument, specifically the Popes Creek watershed, serves as a reference system for environmental studies in the Chesapeake Bay region. Sediment sequences have recorded the history of farming and development beginning in colonial times. The farming activities and development in the Popes Creek watershed occurred at a much lower level than similar coastal plain watersheds in the area. The sediment sequence in Popes Creek watershed, which is geologically similar to other systems in the Chesapeake Bay region, has provided baseline information for the studies that examine the affects of human activities on natural processes.

Seismicity

Brief Description:
Crustal movements along strike-slip, normal, and thrust faults cause shallow-focus earthquakes (those with sources within a few tens of kilometers of Earth's surface), though they can also be human-induced. They can result in marked temporary or permanent changes in the landscape, depending on the magnitude of the earthquake, the location of its epicenter, and local soil and rock conditions [see surface displacement]. Deep-focus earthquakes (below about 70 km), unless of the highest magnitude, are unlikely to have serious surface manifestations.

To avoid, reduce, or warn of environmental impacts, it is necessary to know the size, location, and frequency of seismic events. These parameters can identify active faults and the sense of motion along them. Also of great importance is the spatial pattern of seismicity, including the presence of seismic gaps, and the relationship to known faults and active volcanoes. At least three, and generally many more, monitoring sites are required to determine the necessary parameters.

Seismic observations constitute one of the oldest forms of systematic monitoring of earth processes. There are now in operation many national, regional, and international seismic networks, which provide information about the location, size, and motion of earthquakes anywhere in the world. However, shallow- focus tremors of lower magnitude, may not be detected by these means, and must be monitored more closely, on a local basis. Seismic hazard maps can be constructed to identify areas at varying risk from earthquake damage.

Significance:
Earthquakes constitute one of the greatest natural hazards to human society. Surface effects include uplift or subsidence, surface faulting, landslides and debris flows, liquefaction, ground shaking, and tsunamis ("tidal" waves caused by undersea tremors). Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occur.

Human Influence:
Earthquakes are predominantly natural events. However, shallow-focus seismic tremors can be induced by human actions that change near surface rock stresses or fluid pressures. These actions include: extracting or injecting water, gas, petroleum, or waste fluids into the ground for storage or for secondary hydrocarbon recovery; mining or quarrying activities; and loading the surface with large water bodies (reservoirs). Underground explosions, particularly for nuclear testing, can also generate seismic events. Deep injection of water at the Potash Mine on the boundary of Canyonlands National Park is known to induce earthquakes.

Shoreline position

Brief Description:
The position of the shoreline along ocean coasts and around inland waters (lakes) varies over a broad spectrum of time scales in response to shoreline erosion (retreat) or accretion (advance), changes in water level, and land uplift or subsidence [see relative sea level; surface displacement]. Long-term trends in shoreline position may be masked in the short term by variations over periods of days to years, related, for example, to individual storms, changes in storminess, and El Niño/Southern Oscillation effects. Shoreline position reflects the coastal sediment budget, and changes may indicate natural or human-induced effects alongshore or in nearby river catchments. The detailed shape and sedimentary character of a beach (e.g., beach slope, cusp dimensions, bar position and morphology, barrier crest and berm elevation, sediment size and shape) are highly sensitive to oceanographic forcing, including deep-water wave energy, nearshore wave transformation, wave setup, storm surge, tides, and nearshore circulation: morphodynamic adjustments and feedbacks are common. Qualitative assessments of shoreline morphology can be used as a proxy for shore-zone processes, partially substituting for more quantitative measures of shoreline change where these are not available.

Significance:
Changes in the position of the shoreline affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal settlements to know if local shorelines are advancing, retreating, or stable.

Human Influence:
Erosion and sediment accretion are on going natural processes along all coasts. Human activities (e.g., dredging, beach mining, river modification, installation of protective structures such as breakwaters, removal of backshore vegetation, reclamation of nearshore areas) can profoundly alter shoreline processes, position, and morphology, in particular by affecting the sediment supply.

In Fire Island National Seashore, a groin was installed to protect a water tower at Ocean Beach from erosion by currents, tides, and waves. The effect of the groin was to cause accelerated erosion downshore. This retreat of shoreline continued to migrate downshore through the barrier island system at a rate of one kilometer per year, holding the shape of an eight-foot scarp in the sand. Rough calculations estimate human-induced changes to the shoreline position amount to approximately two meters of beach recession in the last 45-50 years.

Slope failure

Brief Description:
There are many ways in which slopes may fail, depending on the angle of slope, the water content, the type of earth material involved, and local environmental factors such as ground temperature. Slope failure may take place suddenly and catastrophically or may be more gradual. Slope failure results in landslides, debris and snow avalanches, lahars, rock falls, flows (debris, quick clay, loess, and dry or wet sand and silt), slides (debris, rock), topples, slumps (rock, earth), and creep.

Special conditions and processes exist in permafrost terrains. Landslides and mudflows of permafrost regions are mobilized and shaped by the freezing and thawing of pore water in the active layer, the base of which acts as a shear discontinuity. Failure here can occur on slopes as low as 1°. Gelifluction (a form of solifluction, the slow downslope movement of waterlogged soil and surficial debris) is the regular downslope flow or creep of seasonally frozen and thawed soils. Gentle to medium slopes with blankets of loose rock fragments overlying frozen ground may be subject to mass movements such as rock glaciers and rock streams or kurums [see frozen ground activity]. Catastrophic slope failure here can expose new frozen ground, setting off renewed mass wasting.

Three parameters are particularly important for monitoring all kinds of mass movements:

1. Ground cracks are the surface manifestation of a variety of mass movements. In plan, they are commonly concentric or parallel, and have widths of a few centimeters and lengths of several meters, which distinguishes them from the much shorter desiccation cracks [see desert surface crusts and fissures]. The formation of cracks and any increase in their rate of widening is a common measure of impending slope failure.
2. The appearance of and increases in ground subsidence or upheaval is also a good measure of impending failure.
3. The area of slope failure is a measure of the extent of landsliding in any region. Changes over time may both reflect significant environmental stresses (e.g., deforestation, weather extremes) and provide important clues about landscape and ecosystem degradation.

Climate change may accelerate or slow the natural rate of slope failure, through changes in precipitation or in the vegetation cover that binds loose slope materials. Wildfires can also promote mass movements by destroying tree cover. However, it is difficult to generalize where information is lacking on the present distribution and significance of landslides because many parameters, in addition to climate change, contribute to slope stability.

Significance:
Slope failure causes death and property damage. Damage to ecosystems has not generally been documented, but landslides may destroy habitats, for example by blocking streams and denuding slopes.

Human Influence:
Slope failure is a natural process that may be induced, accelerated, or retarded by human actions. Human influences include:

1. Removal of lateral support through human actions such as cutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs.
2. Adding weight to slopes by human actions such as landfills, stockpiles of ore or rock, waste piles, construction of heavy building and other structures, fill, and retaining walls.
3. Vibrations from explosions, machinery, road and air traffic.
4. Decrease of underlying support through mining.
5. Lubricating slope materials with water leaking from pipelines, sewers, canals, and reservoirs.

The Grand Ditch in Rocky Mountain National Park is a 16.2-mile aqueduct that diverts water from the West Slope streams to farms, ranches, towns, and cities on the eastern plains. Completed in 1936, it is one of the earliest transmountain diversions in Colorado. The Grand Ditch, which is cut into the mid- to upper slopes of the Never Summer Mountains, causes landslides in the upper Colorado River from undercutting the hillslope. Landslide material deposited in the Grand Ditch is side cast by bulldozers downslope when the ditch is cleaned annually.

Soil and sediment erosion

Brief Description:
Erosion—the detachment of particles of soil and surficial sediments and rocks—occurs by hydrological (fluvial) processes of sheet erosion, rilling and gully erosion, and through mass wasting and the action of wind [see sediment geochemistry and stratigraphy; stream sediment storage and load; wind erosion]. Erosion, both fluvial and eolian (wind), is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands, the rate of soil and sediment erosion approaches that of denudation (the lowering of Earth's surface by erosional processes). In many areas, however, the storage of eroded sediment on hillslopes of lower inclination, in bottomlands, and in lakes and reservoirs, leads to rates of stream sediment transport much lower than the rate of denudation.

When runoff occurs, less water enters the ground, thus reducing plant productivity. Soil erosion also reduces the levels of the basic plant nutrients needed for growth, and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use, and provides an important transporting medium for a wide range of chemical pollutants that are readily sorbed on sediment surfaces. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals, and fish.

Significance:
Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems.

Human Influences:
Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (ploughing, irrigation, grazing), forestry, construction, surface mining, and urbanization. Humans induce both water and wind erosion, which may result in chemical and physical deterioration of soil [see soil quality].

Within Sleeping Bear Dunes National Seashore, there are 11 major gravel and sand extraction pits or topsoil mining sites. The largest site is a 65-acre topsoil-mining site (STAN site); another site covers 40 acres on Scenic Drive.

Soil quality

Brief Description:
Soils vary greatly in time and space. Over time-scales relevant to geoindicators, they have both stable characteristics (e.g., mineralogical composition and relative proportions of sand, silt, and clay) and those that respond rapidly to changing environmental conditions (e.g., ground freezing). The latter characteristics include soil moisture and soil microbiota (e.g., nematodes, microbes), which are essential to fluxes of plant nutrients and greenhouse gases. The soils of boreal regions are estimated to hold the equivalent of some 60% of the current atmospheric carbon: long-term warming is expected to increase decomposition and drying, thus potentially releasing huge volumes of methane and CO_2.

Most soils resist short-term climate change, but some may undergo irreversible change such as lateritic hardening and densification, podsolization, or large-scale erosion. Soil properties and climatic variables such as mean annual rainfall and temperature can be related by mathematical functions known as climofunctions.

Chemical degradation takes place because of depletion of soluble elements through rainwater leaching, overcropping and overgrazing, or because of the accumulation of salts precipitated from rising groundwater or irrigation schemes. It may also be caused by sewage containing toxic metals, precipitation of acidic and other airborne contaminants, as well as by persistent use of fertilizers and pesticides. A widespread problem is the retention in the soil organic matter and clay minerals of potentially toxic metals and radionuclides (e.g., Cu, Hg, Pb, Zn, 226Ra, 238U). These and other chemical components may be catastrophically released as what are commonly referred to as "chemical time bombs" where the pH of the soil is decreased by acidification or where other environmental disturbances (e.g., erosion, drought, land use change) intervene. Soils also act as a primary barrier against the migration of organic contaminants into groundwater. Key indicators are pH, organic matter content, sodium absorption ratio, cation exchange capacity, and cation saturation.

Physical degradation results from land clearing, and erosion and compaction by machinery. Soil structure may be altered so that infiltration capacity and porosity are decreased, and bulk density and resistance to root penetration are increased. Such soils have impeded drainage and are quickly saturated: the resultant runoff can cause accelerated erosion and transport of pollutants such as pesticides [see soil and sediment erosion]. The key soil indicators are texture (especially clay content), bulk density, aggregate stability and size distribution, and water-holding capacity.

Significance:
As one of Earth's most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants; they store moisture and nutrients; and they are important sources and sinks for CO_2, methane, and nitrous oxides. Soils are a key system for the hydrological cycle [see groundwater chemistry in the unsaturated zone]. Soils also provide an archive of past climatic conditions and human influences.

Human Influences:
Soils may be degraded or enhanced by both natural processes and human activities. Human activities influence soil properties by causing increases in bulk density from agricultural tillage and road operations and in acidification from inorganic fertilizers and acid rain. Soil degradation is one of the largest threats to environmental sustainability.

Streamflow

Brief Description:
Streamflow varies with the volume of water, precipitation, surface temperature, and other climatic factors. For most streams (rivers), the highest water discharge is found close to the sea, but in arid regions discharge decreases naturally downstream. Land use in drainage basins also strongly affects streamflow. Major streamflow regimes include glacial, nival, dry tropical, monsoon, equatorial, and desert. Reversals in streamflow, in conjunction with indirect methods of paleoflood studies and paleohydrology, yield long-term indicators of changes in discharge that are valuable for responses to flooding, estimating long-term trends in water and sediment discharges, and for distinguishing possible long-term climate change.

Significance:
Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Human Influences:
Natural variations in streamflow predominate, but they can be strongly modified by human actions, such as dams and reservoirs, irrigation, and diversion for use outside the watershed.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. These streams drain the Pioneer Mountains in the north end of the park. Diversion of streamflow in Little Cottonwood Creek began in the 1930s for park operations. Water demand was low until the late 1950s when the visitor center complex was built. It is estimated that peak consumption occurred in the late 1960s when over 50% of the streamflow was diverted out of the channel. At present (2000) this use has decreased to approximately 30% due to the reduction in the area of irrigated lawns.

Stream channel morphology

Brief Description:
Alluvial streams (rivers) are dynamic landforms subject to rapid change in channel shape and flow pattern. Water and sediment discharges determine the dimensions of a stream channel (width, depth, and meander wavelength and gradient). Dimensionless characteristics of stream channels and types of pattern (braided, meandering, straight) and sinuosity are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load in terms of the ratio of suspended to bed load [see stream sediment storage and load]. Dramatic changes in stream bank erosion within a short time period indicate changes in sediment discharge.

Significance:
Channel dimensions reflect magnitude of water and sediment discharges. In the absence of hydrologic and streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, place significant limits on land use, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

Human Influences:
Significant changes in stream dimensions, discharge, and pattern may reflect human influences such as water diversion and increased sediment loads resulting from land clearance, farming, or forest harvesting. Such variations are also responsive to climatic fluctuations and tectonics.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. There is evidence that the lower portion of Little Cottonwood Creek was historically diverted out of its natural channel. The creek makes a 90º bend, and a line of dead cottonwood trees and a ground depression indicate where the channel used to be. The channel morphology of Leach Creek has also been altered. There are old impoundments or control structures in the upper portion of the creek. A dry channel in the lower portion indicates that the creek was historically diverted out of its natural channel. Both creeks continue to be diverted out of their original channels (2000).

Stream sediment storage and load

Brief Description:
The load (discharge, tonnes/year) or yield (tonnes/km2/year) of sediment (in suspension and as bed load of sand and gravel) through stream (river) channels reflects upland erosion within the drainage basin and change in storage of sediment in alluvial bottomlands [see soil and sediment erosion]. In turn, climate, vegetation, soil and rock type, relief and slope, and human activities such as timber harvesting, agriculture, and urbanization influence stream sediment storage and load. Much of the sediment eroded from upland areas is deposited (stored) on lower hillslopes, in bottomlands, and in lakes and reservoirs. Flash floods in ephemeral desert streams may transport very large sediment loads, accounting for unforeseen sedimentation problems in dryland stream reservoirs.

Significance:
Sediment load determines channel shape and pattern [see stream channel morphology]. Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography, and land use. Fluctuations in sediment discharge affect a great many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. For example, to reproduce effectively, salmon and trout need gravel stream beds for spawning and egg survival; silt and clay deposits formed by flooding or excessive erosion can destroy these spawning beds. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

Human Influences:
Stream sediment storage and load is influenced strongly by human actions, such as in the construction of dams and levees, forest harvesting, and farming in drainage basins.

Subsurface temperature regime

Brief Description:
Temperatures in boreholes a few hundred meters deep can be an important source of information on recent climatic changes because the normal upward heat flow from Earth's crust and interior is perturbed by the downward propagation of heat from the surface. As temperature fluctuations are transmitted downward, they become progressively smaller, with shorter-period variations attenuating more rapidly than longer ones. Although seasonal oscillations may be undetectable below about 15 m, century-long temperature records may be observed to depths of 150 m or so. Bedrocks thus selectively retain the long-term trends required for reconstructing climate change.

The surface temperature is strongly affected by local factors such as thickness and duration of snow cover, type of vegetation, properties of organic soil layers, depth to the water table, and topography. It influences, in turn, a wide range of ground and surface processes, particularly in the near-surface portions of permafrost [see frozen ground activity]. Below the active layer, where ground temperature fluctuates seasonally as thawing and freezing take place, long-term temperature variations may be recorded. Here, repeated measurements of soil temperature at fixed locations can reveal both the long-term dynamics of seasonally frozen ground and long-term climatic fluctuations, though the conversion of ground temperature to climate history is a complex matter.

Significance:
The thermal regime of soils and bedrocks exercises an important control on the soil ecosystem, on near-surface

chemical reactions (e.g., involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity, and decay of plants; the availability and retention of water; the rate of nutrient cycling; and the activities of soil microfauna. It is also of major importance as an archive of climate change, indicating changes in surface temperature over periods of up to 2-3 centuries, for example in regions without a record of past surface temperatures. In permafrost, the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

Human Influence:
The subsurface temperature regime reflects both the natural geothermal flux from Earth's interior and the surface temperature. The latter can be modified by human actions, such as land clearing, wetland destruction, agriculture, deforestation, flooding of land for reservoirs, or development of large settlements that give rise to a "heat island" effect.

Surface displacement

Brief Description:
Earth's surface is subject to small but significant displacements (uplift, subsidence, lateral movement, rotation, distortion, dilation) that affect elevation and horizontal position. These movements result from active tectonic processes, collapse into underground cavities, or the compaction of surficial materials. Sudden movements may be caused by faulting associated with earthquakes [see seismicity], and from the collapse of rock or sediment into natural holes in soluble rocks (e.g., salt, gypsum, limestone) [see karst activity], or into cavities produced by mining of near-surface rocks (especially coal) and solution-mining of salt. Slower local subsidence may also be induced by: fluid withdrawal (gas, oil, groundwater, geothermal fluids); densification or loss of mass in peat being developed for agriculture; drainage of surface waters from wetlands, which can cause oxidation, erosion, and compaction of unconsolidated soils and sediments [see wetlands extent, structure, and hydrology]; and filtration of surface water through porous sediments such as loess. On a much larger scale, the land surface elevation responds slowly to plate movements, compaction of sedimentary basins, and glacial rebound.

Fissures and faults can develop suddenly during earthquakes and as a result of volcanic processes and landsliding, or more slowly as a result of differential compaction during subsidence. In arid and semi-arid terrains, fissures up to several kilometers long and a few centimeters wide may be rapidly eroded by surface run-off to gullies.

Significance:
Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically-induced uplift raises intertidal ecosystems above sea-level. Moreover, extraction of fluids beneath urban areas can induce land subsidence and cause flooding, especially of coastal communities near sea-level. Subsidence damages buildings, foundations, and other built structures.

Human Influence:
Surface displacements are natural phenomena associated with plate movements, glacial rebound, and faulting, but human activities such as extraction of groundwater, oil, and gas can also induce surface subsidence.

In Cape Cod National Seashore, surface displacement is linked to other geoindicators: relative sea level and wetlands. Ditching and diking of formerly tidal wetlands have caused significant subsidence within the Seashore. The subsidence is significant not with respect to aerial extent, but to the sensitivity of habitats affected and the challenge subsidence poses to restoration efforts.

Surface water quality

Brief Description:
The quality of surface water in rivers and streams, lakes, ponds, and wetlands is determined by interactions with soil, transported solids (organics, sediments), rocks, groundwater, and the atmosphere. It may also be significantly affected by agricultural, industrial, mineral and energy extraction, urbanization, and other human actions, as well as by atmospheric inputs. The bulk of the solutes in surface waters, however, are derived from soils and groundwater baseflow where the influence of water-rock interactions is important [see groundwater quality; karst activity; soil and sediment erosion; soil quality; streamflow; wetlands extent, structure, and hydrology].

Significance:
Clean water is essential for the survival of all forms of life. Most is used for irrigation, with lesser amounts for municipal, industrial, and recreational purposes; only 6% of all water is used for domestic consumption. Pathogens such as bacteria, viruses, and parasites are among the world's most dangerous environmental pollutants and cause water-borne diseases. Water quality data are essential for the implementation of responsible water quality regulations, for characterizing and remediating contamination, and for the protection of the health of humans and other organisms.

Human Influence:
The water quality of a lake, reservoir, or river can vary in space and time according to natural morphological, hydrological, chemical, biological, and sedimentological processes (e.g., changes of erosion rates). Pollution of natural bodies of surface water is widespread because of human activities, such as disposal of sewage and industrial wastes, land clearance, deforestation, use of pesticides, mining, and hydroelectric developments.

Trespass cattle at springs in Arches National Park raise a concern regarding maintenance of good water quality.

Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination.

Herbicides to decrease the number of tamarisk stands may cause water quality problems associated with streams and springs in Arches National Park, Canyonlands National Park, and Natural Bridges National Monument.

Volcanic unrest

Brief Description:
Eruptions are almost always preceded and accompanied by volcanic unrest, indicated by variations in the geophysical and geochemical state of the volcanic system. Such geoindicators commonly include changes in seismicity, ground deformation, nature and emission rate of volcanic gases, fumarole and/or ground temperature, and gravity and magnetic fields. Volcanic unrest can also be expressed by changes in temperature, composition, and level of crater lakes, and by anomalous melting or volume changes of glaciers and snow fields on volcanoes. When combined with geological mapping and dating studies to reconstruct comprehensive eruptive histories of high-risk volcanoes, these geoindicators can help to reduce eruption-related hazards to life and property. However, not all volcanic unrest culminates in eruptions; in many cases the unrest results in a failed eruption in which the rising magma does not breach the surface and erupt.

Significance:
Natural hazards associated with eruptions pose a significant threat to human and animal populations. Before 1900, two indirect hazards—volcanogenic tsunamis and post-eruption disease and starvation—accounted for most of the eruption-associated human fatalities. In the 20th century, however, direct hazards related to explosive eruptions (e.g., pyroclastic flows and surges, debris flows, mudflows) were the most deadly hazards.

Human Influence:
None. Volcanism is a natural process that has operated since the formation of Earth. Although a few attempts have been made to divert lava flows, humans have had no influence whatsoever on the underlying causes of volcanism.

Wetlands extent, structure, and hydrology

Brief Description:
Wetlands are complex and sensitive ecosystems, characterized by a water table at or near the land surface for some part of the year, by soil conditions that differ from adjacent uplands, and by vegetation adapted to wet conditions. Wetlands are usually classified on the basis of their morphology and vegetation and, to a lesser extent, their hydrology. Though definitions vary, the following types are widely recognized: coastal salt and freshwater marshes; swamps (mangrove, shrub, and wooded); wet grasslands, meadows, and prairies; and peatlands (landforms in which organic sediments have accumulated to depths in excess of 30-50 cm), including mires, moors, muskeg, bogs, and fens.

The areal extent, distribution, and surface and internal structures of a wetland can be altered by many processes, such as organic and inorganic sediment deposition and erosion, paludification (lateral spread), terrestrialization (colonization of open water by wetland plant communities), and changing hydrology. In the case of coastal wetlands, saltwater intrusion and changes in sea level can also be important [see relative sea level; shoreline position].

Hydrological relationships play a key role in wetland ecosystem processes, and in determining structure and growth. Different wetlands have a characteristic hydroperiod, or seasonal pattern of water levels, that defines the rise and fall of surface and subsurface water. An important geoindicator is the water budget of a wetland, which links inputs from groundwater, runoff, precipitation, and physical forces (wind, tides) with outputs from drainage, recharge, evaporation, and transpiration. Annual or seasonal changes in the range of water levels affect visible surface biota, decay processes, accumulation rates, and gas emissions. Such changes can occur in response to a range of external factors, such as fluctuations in water source (river diversions, groundwater pumping), climate, or land use (forest clearing). Waters flowing out of wetlands are chemically distinct from inflow waters, because a range of physical and chemical reactions take place as water passes through organic materials, such as peat, causing some elements (e.g., heavy metals) to be sequestered and others (e.g., DOC, humic acids) to be mobilized. A baseline of wetland conditions may be established through a paleoecological study to investigate whether a present-day wetland is stable or actively evolving, and if so in what direction and at what rate.

Significance:
Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large- and small-scale environmental processes by altering downstream catchments. The dissolved carbon burden of wetlands may affect downstream waters, for example by acid drainage. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, such as Hg, and serving as flood buffers and, in coastal zones, as storm defenses and erosion controls.

Wetlands can act as carbon sinks, storing organic carbon in waterlogged sediments. Even slowly growing peatlands may sequester carbon at between 0.5 and 0.7 tonnes/ha/yr. Wetlands can also be a carbon source, when it is released via degassing during decay processes, or after drainage and cutting, as a result of oxidation or burning.

Human Influence:
Wetlands develop naturally in response to morphological

and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (e.g., coastal erosion), or human activity (draining, channeling of local rivers, water abstraction and impoundment, forest clearance). Wetlands can be lost to drainage for agriculture or settlement or to harvesting for commercial purposes.

Diking and drainage in the late 19th century and freshwater impoundment in the mid-20th century have interrupted the evolution of salt marshes in the upper Pamet River in Cape Cod National Seashore. These hydrologic alterations have caused vegetation to shift from salt-tolerant grasses to salt-intolerant herbs, trees, and shrubs and have caused the wetland surface to subside well below the elevation of modern, undiked marshes.

Wind erosion

Brief Description:
The action of wind on exposed sediments and friable rock formations causes erosion (abrasion) and entrainment of sediment and soil particles [see dust storm magnitude, duration, and frequency]. Eolian action also forms and shapes sand dunes, yardangs (streamlined bedrock hills), and other landforms. Subsurface deposits and roots are commonly exposed by wind erosion. Wind can also reduce vegetation cover in wadis and depressions, scattering the remains of vegetation in interfluves. Stone pavements may result from the deflation (removal) of fine material from the surface leaving a residue of coarse particles. Blowouts (erosional troughs and depressions) in coastal dune complexes [see dune formation and reactivation] are important indicators of changes in wind erosion. The potential for deflation is generally increased by shoreline erosion or washovers, vegetation die-back (due to soil nutrient deficiency or to animal activity), and human actions such as recreation and construction.

Significance:
Changes in wind-shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of environmental change in arid lands. Wind erosion also affects large areas of croplands in arid and semi-arid regions, removing topsoil, seeds, and nutrients.

Human Influence:
Eolian erosion is a natural phenomenon, but the surfaces it acts upon may be made vulnerable by human actions, especially those, such as cultivation and over-grazing, that result in the reduction of vegetative cover.

Currently in Cape Cod National Seashore, human actions [e.g., use of ORVs (off- road vehicles) and the proliferation of social trails] influence wind erosion. Degraded areas are limited, but it is of high management significance because of the impacts on popular areas, such as Herring Cove. Aerial photographs revealed a “spider web” of social trails in this area.

Appendix B: Human Influences

The term "human influences" has purposefully been selected in order to explore the full breath of human activities, both inside national parks and external to the park boundaries.

Adjacent land use, consumptive activities, administrative practices, and visitor use can all influence earth surface processes. An effective way to illustrate human influences on earth surface processes is to go through some examples. This is not a comprehensive treatment, and these examples do <u>not</u> occur in all parks. These examples are provided to raise awareness, stimulate the reader's thinking, and perhaps cause the reader to contemplate additional cases from his or her own experience.

Land Use

Agriculture
Intense use can cause loss of soil, erosion, and dust storms. Use of pesticides can affect both surface water and groundwater quality.

Grazing
Overgrazing can cause loss of vegetation, invasion of exotic species, soil erosion, and nutrient loss.

Forestry
Intense logging or clear cutting creates conditions for increased erosion; eroded and transported sediment can cause increased sediment loading in streams, which could affect fluvial habitat.

Water impoundment
This has the potential to affect one segment of a stream or river or an entire watershed. Controlled volume of flow does not duplicate natural events, such as floods and drought. It can affect the sediment load, change the stream morphology, and alter the habitat that is dependent on a fluvial system.

Urbanization
This can cause a host of impacts, but a few stand outs are: change in drainage patterns because of impervious surfaces (streets, parking lots, pavement, buildings), increased erosion, affects on surface and groundwater quality and quantity, release of toxins into the air, increased humidity in arid regions.

Alterations to shorelines
Dredging, beach mining, river modification, installation of protective structures, and removal of back-shore vegetation can potentially alter shoreline processes, position, and morphology by changing the sediment supply, transport, and erosion.

Consumptive Use

Groundwater withdrawal
This sustainable, renewable resource can become a non-renewable, mined one, if groundwater withdrawal exceeds recharge. Mining groundwater is terminal and affects and entire ecosystem (both living and non-living components). Where withdrawal has been intense for decades, the surface has been known to collapse (subside) over many acres to depths of over ten feet.

Oil and gas production
This can cause surface subsidence and cause contamination of water aquifers and cave & karst systems. Oil and gas operations can leave a considerable "footprint" on the land, such as roads (created during seismic tests and well operation), pipelines, facilities, storage tanks, and well pads.

Mining (open pit and underground)
It can reconfigure the landscape over large areas bringing significant and permanent change to the landscape. It can affect groundwater by releasing heavy metals or other chemicals into the system.

Mineral Materials Mining
If performed in sensitive ecosystems or with respect to volume of material removed, the quarrying of stone, mining of gravel, and borrowing of soil can impact geologic process.

Extirpation of species
This can affect both the living and non-living components of an ecosystem. Take the elimination of beaver from an ecosystem, for example. This can alter water impoundment, sediment load, timing of sediment release, and stream channel morphology.

Administrative Use

Roads & bridges
Often constructed with little or no consideration for natural processes. Roads can disrupt drainage, cause erosion, and create hillslope instability. The abutments for bridges can change the flow and morphology of streams and rivers.

Parking lots
Construction, location, and drainage off parking lots can cause harm. Large paved areas deprive the surface of an opportunity to absorb precipitation. Water flowing from parking lots can cause erosion and gullying if not properly directed. Runoff pollution affects surface and groundwater.

Facilities placed over karst and caves
Contaminants and runoff from restrooms and other water usage can reach cave and karst systems below Earth's surface and cause damage to the fragile subterranean ecosystem.

Water consumption
Parks located in arid environments need special consideration for all aspects of water usage (restrooms, watering lawns, domestic use for staff, maintenance shops, etc.)

Trails
If they are poorly located with respect to soil, rockwalls, wetlands, and sensitive vegetation, they have the potential to exacerbate erosion, rock falls, and slope instability. The placement of snowmobile trails can influence slope stability and cause avalanches.

Armoring
Through engineering efforts, humans have attempted to impose stability on naturally dynamic and ever-changing environments along streams, rivers, coastlines, and shorelines. Structures interfere with the transport of sand and sediment and aggravate erosion over the long-term.

Planting exotic species
Planting non-native species on sand dunes to hold them in place disrupts eolian processes that drive an ecosystem.

Fire
Fires directly affect slope stability and can cause debris flows on steep slopes.

Visitor Use

Compaction of soils
Over use by recreationists (hiking, horseback riding, mountain biking, OHV's) can compact soil, which diminishes its capability to function and maintain itself as a viable part of the ecosystem.

Social trails
Depending on the fragile nature of the environment, wandering off-trail can seriously damage fragile resources (caves, wetlands, soil crusts, cinder cones, tundra, etc.)

Touching fragile features
A number of geologic features have taken ye
ars to form through geologic processes, and although seemingly rock-hard, they may be fragile. Examples include stalactites and stalagmites in caves. Also included are erosional features, such as arches, bridges, hoodoos, and badlands. Crystals are another example. Visitors touching or climbing on all these features can cause irreparable damage.

Power boating
Over a period of time, wakes from small and large boats alike can contribute to shoreline erosion. Fuel contamination can affect water quality.

Appendix C: Introducing Geoindicators

What are Geoindicators?

Geoindicators constitute an approach for identifying rapid changes in the natural environment. An international Working Group of the International Union of Geological Sciences (IUGS) developed geoindicators in order to access common geological processes occurring at or near Earth's surface that may undergo significant change in magnitude, frequency, trend, or rates, over periods of 100 years or less. Geoindicators measure both catastrophic events and those that are more gradual but evident within a human lifespan. Some geoindicators can provide a record of natural events through time.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

Why are Geoindicators important?

Ecosystem management, reporting, and planning generally focus on biological issues such as biodiversity, threatened and endangered species, exotic species, and biological and chemical parameters relating to pollution (e.g., air and water quality). Much less attention is paid to the physical processes that shape the landscape—the natural, changing foundation on which humans and all other organisms live and function.

Geoindicators help answer NPS resource management questions about what is happening to the environment, why it is happening, and whether it is significant. They establish baseline conditions and trends, so that human-induced changes can be identified. Applying the geoindicators approach will provide science-based information to support resource management decisions and planning. Geoindicators help non-geoscientists focus on key geological issues, help parks anticipate what changes might occur in the future, and identify potential management concerns from a geological perspective.

Geology and geological processes are integral to park management and planning. For example, the underlying geology and soils influence natural vegetation patterns, and in turn exert a control on biological communities. Geological processes can affect park roads, infrastructure, and facilities. When measures of natural landscape change are omitted from monitoring and planning, the assumption that natural systems are stable, fixed, and in equilibrium is perpetuated. Natural systems are dynamic, and some may be chaotic; change is the rule, not the exception. Monitoring the abiotic components of ecosystems using geoindicators will help to emphasize this point.

The geoindicators approach can be a useful reminder both of the prevalence of natural fluctuations and of the difficulty of separating them from human-induced environmental change. Using geoindicators shifts management actions from response (crisis mode) to long-range planning, so issues can be recognized before they become concerns. Geoindicators may also prove to be useful tools for enhancing interdisciplinary research and communication, a way to connect with others concerned with environmental issues and problems.

How do Geoindicators fit into the National Park Service's strategic plan?

In 1999, the NPS Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, "Geological processes in 75 parks (36% of 270 natural resource parks) are inventoried and human influences that affect those processes are identified." This goal was designed to increase understanding of geological processes and their functions in ecosystems and to help park managers make more informed science-based management decisions.

This goal is intended to be the first step in a process that will lead to inventory, monitoring, and research, and ultimately focus on the mitigation or elimination of human activities that severely impact geological processes, harm geologic features, or cause critical imbalance in ecosystems.

What is the purpose of a Geoindicators scoping meeting?

The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. Pertinent human influences may include visitor impacts, park management practices and developments, land use adjacent to parks (e.g., pollutants, timber harvest), and global issues (e.g., industrial dust from China).

In addition, resource management issues related to geology and geological processes will be identified; and inventory, monitoring, and research studies that can provide scientific data to be used in making management decisions will be recommended.

How does the Geoindicators scoping process work?

The GRD coordinates efforts between park resource managers and geologists (from federal and state agencies and academia) through scoping meetings that are held in national parks. The scoping meetings are designed to use the participants' current expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas. For park staff, the scoping meetings foster a better understanding of the physical resources and geological processes in the park. For scientists, the scoping meetings foster an awareness of management issues and the decision-making and planning processes preformed by park staff.

The field trip portion of a scoping meeting highlights the park's setting and geology, as well as key resource management issues related to geological processes. During the discussion portion of a scoping meeting, selected geoindicators—specific to a park's setting—guide and focus the dialog.

The following questions are addressed during the group discussion of a scoping meeting. The answers are rated and prioritized.

➤ What are the significant geological processes in the park's ecosystems? Why are they significant?

➤ Which of these geological processes is being influenced by human activities both from inside and outside the park?

➤ How significant to park management are the identified geological processes and associated human influences?

➤ What sort of geological baseline data would benefit the park?

➤ What geoindicators should be monitored in the park? What protocols are recommended and who are the geoscientists to contact?

➤ Where are the information gaps? What studies or research are recommended?

➤ What information should be included in park planning documents?

What are the outcomes of a Geoindicators scoping meeting?

Scoping meetings provide an opportunity for park staff and geologists to connect and build relationships. This is significant because many park managers do not have easy access to geological expertise, and most do not have geologists on staff or in their regional offices.

Managers from participating parks will receive a summary report that highlights the recommendations identified during the scoping meeting. Recommendations include inventory and monitoring—which will provide information to use for park planning and decision-making—and research topics that will fill information gaps.

Where can I get more information?

➤ Web site about geologic resource monitoring in the U.S. National Parks: http://www2.nature.nps.gov/grd/geology/monitoring/index.htm.

➤ Detailed descriptions of the 27 geoindicators: http://www2.nature.nps.gov/grd/geology/monitoring/parameters.htm.

➤ Web site of the IUGS Geoindicators Initiative: http://www.lgt.lt:8080/geoin/welcome.

Appendix D:
Species Don't Stand Alone - Geology's Role in Ecosystems

Ecology's fundamental insight for ecosystem management is that species do not stand alone. Organisms are dynamically and interactively enmeshed in the abiotic ecosystem matrix. Increasingly, ecologists and land- management agencies are recognizing that species—the living components of ecosystems—cannot be conserved without conserving the non-living components, which help shape ecosystem structure and function (Pickett et al., 1992; Christensen et al., 1996). As "matrix sciences," physical sciences such as geology, soil science, hydrology, and climatology play a fundamental role in conservation and ecosystem management.

The founder of modern ecosystem ecology was a soil scientist, Hans Jenny (Vitousek, 1994), and James Lovelock, a geophysicist, conceptualized Planet Earth as a functional ecosystem composed of functional subsystems (Rowe, 2001). Yet despite these historical connections between the sciences and the tremendous importance of the matrix sciences to ecosystem studies, most ecosystem mangers have not traditionally integrated the biological and physical sciences in resource managment. The problem may be that most ecosystem managers/ecologists have been educated in biology departments and trained to focus on species (Rowe, 2001). Thus, the abiotic components of an ecosystem often enter management discussions as an afterthought, of secondary importance and vaguely associated with the fuzzy term "habitat," if they enter the discussion at all.

Over the last two decades, however, the focus of land management has slowly been shifting to a truly integrated, ecosystem approach—one that recognizes that species do not stand alone—and incorporates biological, geological, and social components (Figure 1). This change is particularly important as resource managers strive to gain greater predictive and mechanistic understanding of ecosystem responses to human activities. This approach identifies a need to devote increased attention to the geosciences, and especially to the interactions between the geological and biological systems.

Geological processes create topographic highs and lows; impact water and soil chemistries; influence the fertility of soils, the stability of hillsides, and the flow styles of surface water and groundwater (Swanson et al., 1988). These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts. Likewise, biological processes affect geological processes. Biological activity contributes to soil formation and soil fertility, controls hillside erosion, traps blowing sand to form dunes, stabilizes drainages, and attenuates floods.

The geological resources of a park—soils, caves, glaciers, streams, springs, volcanoes, etc.—provide the physical foundations required to sustain the biological system. Human influences on geological processes and alteration of geological features inevitably affect habitat conditions. For example, the channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Smith, 1998; Steen, 1999). In Jean Lafitte National Historical Park and Preserve, externally triggered land subsidence is raising the water level in the park, thereby inundating the swamp forest and reducing habitat for forest-dependent species (Sauier, 1994). Alternatively, a manipulation of the biological system can trigger changes in the geological system that can re -affect the biological system. For example, when beaver are trapped to increase the density of hydrophobic shrub species, the river morphology and sediment transport capacity change, resulting in a redistribution of the types of fish species. Geological resources also influence the impacts of natural variation in factors such as climate or human activity. The availability of water, the stability of soil surfaces, and nutrient supply from weathering rocks are all examples of underlying physical controls on biological processes.

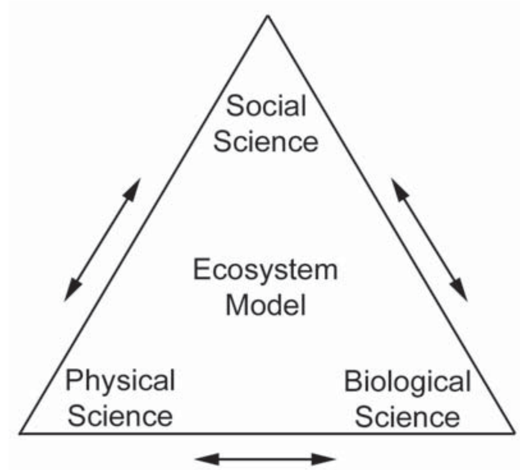


Figure 1. Relationship of component parts to an ecosystem.

A challenge in appreciating the relevance of geology is that geologists often work with very long time scales; whereas, life-science specialists deal with much shorter time scales. In actuality, however, geological processes occur over a variety of temporal and spatial scales. At one end of the temporal spectrum lie the processes that occur over millions of years, such as the rising of a mountain range or creation of an ocean basin. At the other end lie the processes that occur virtually instantaneously (and often catastrophically) such as floods, landslides, and earthquakes. Between these extremes is the constant, continuous evolution of a landscape over days, months, and years. Examples of these are shoreline movement, river transport of sediment, soil formation, and cave development.

Geological processes are as diverse spatially as they are temporally. The absorption of chemical elements by sediment particles may be the key process in determining groundwater chemistries. This process occurs at the microscopic level. In contrast, the geothermal activity at Yellowstone or Lassen Volcanic national parks is related to the movement of tectonic plates at a global scale.

Geological processes that most directly impact biological processes include: stream and groundwater flow, weathering and mass wasting (e.g., landslides, rockfalls), earthquakes, volcanic phenomena (e.g., eruptions, hot springs), and variation in physical and biogeochemical attributes of soils. These processes collectively operate on a variety of time scales, and it is possible for all of these processes to be operating simultaneously in a single park. For example, minor earthquakes usually accompany eruptions in Hawaii Volcano National Park, and the overall event can include landslides, stream diversion by lava flows, and buildup of topography when the lava flows solidify. These processes destroy some habitats while creating others, and introduce new substrates for early successional stages, thus maintaining habitats for early successional species (Parrish and Turner, 2001).

Even seemingly static geological resources contribute to ecosystem mosaics and biodiversity. For example, in Grand Canyon National Park, the nesting sites of spotted owls are restricted to ledges formed in a specific rock layer, the Hermit Shale. Similarly, vegetation distributions in Canyonlands National Park respond to variation in surface soil textures and elemental content. Thus, management of the nesting sites of threatened species and unique native plant habitats requires knowledge of the geological substrate. Identifying that a rock layer is important to an owl species indicates the need for integrated research. An example of floral dependence on geology is the Winkler's cactus, which grows only on the white, powdery soil and pebbles eroded from part of the Morrison Formation in Canyonlands National Park. In this case, not only is the distribution of the rock layer itself important to the plant, but the erosion products are quite fragile, requiring management of both the plant and its delicate habitat (Parrish and Turner, 2001). This same type of abiotic-biotic pattern repeats itself across the entire Colorado Plateau, a region recognized for its high frequency of plant endemism primarily because of the evolutionary constraints posed by extensive exposures of raw geologic substrates (Welsh et al., 1993).

Abiotic ecosystem components, encompassed by the matrix sciences, play central roles in shaping the distribution and dynamics of biotic systems. Nutrient constraints; water availability; disturbances in the form of landslides, floods, droughts, and eolian processes all act to constrain the composition, structure, and productivity of the terrestrial biosphere. These processes also influence the distribution of individual plant and animal species across the landscape and condition the responses of ecosystems to environmental change. In present-day ecosystems, there is tremendous variability across landscapes and through time in the ways that ecosystems respond to changes in species, climatic patterns, and land use; this variability is poorly understood. For example, how will ecosystems, and the goods and services they provide, be differentially affected by the numerous interacting components of global change: increased temperatures and CO_2 concentrations, altered precipitation patterns, and greater frequencies of extreme climatic episodes? This question can no longer be left to the future (McCarty, 2001; Hannah et al., 2002). From a management perspective it is crucial to identify and predict the spatial and temporal variation in both ecological vulnerabilities and services. Improved understanding of this variability would allow for more efficient, cost-effective, and sustainable use of natural resources. One of the primary hindrances to this understanding is the lack of integrative science that could facilitate ecological forecasting. In the face of rapid environmental changes, successful resource management cannot be accomplished without integrating the abiotic matrix sciences with the more-familiar biotic sciences.

These are exciting and stressful times for resource managers, as attempts to counter threats to cherished places and species are made. Disciplinary boundaries, although essential for some purely scientific tasks, are an impediment to understanding complicated issues such as preservation of ecosystems. Human attitudes and past human influences on natural systems are crucial elements in understanding what is happening and what options are available (Ludwig, 2001).

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Appendix E: Park Setting

Colorado National Monument preserves one of the grand landscapes of the American West

In the early part of the last century, citizens of Grand Junction deluged Congress with letters and petitions to declare the area west of town as a national park. The original idea came from the local chamber of commerce, but John Otto became its most avid booster. After tireless campaigning, Colorado National Monument became a reality in 1911. Otto became the monument's first caretaker at a salary of $1 a month. He lived alone out in the wild and desolate canyon country southwest of Grand Junction, and many folks thought he was crazy. Otto continued in this job until the 1920s when, after a quarrel with the National Park Service, he tendered his resignation, which was accepted—it is suspected—with a great deal of relief. Otto retired to California, where he died a pauper in the 1950s. Recently, citizens of Grand Junction traveled to his grave and erected a headstone as a fitting memorial to the man who almost single-handedly brought about the recognition of one of this nation's geologic treasures.

The high country of the monument rises more than 2,000 feet above the Grand Valley of the Colorado River. Situated at the edge of the Uncompahgre Uplift, the monument is part of the greater Colorado Plateau, which also embraces such geologic wonders as the Grand Canyon, Bryce Canyon, and Arches. Bold, big, and brilliantly colored, this plateau-and-canyon country with its towering masses of naturally sculpted rock, embraces 32 square miles of rugged, up-and-down terrain. What the monument lacks in size, it makes up in variety and color of rock formations, beauty, and solitude.

Colorado National Monument is semi-desert land. In the deep canyons, vertical cliff walls and great natural rock sculptures tower overhead on a grand scale. Nowhere is this more true than in Monument and Wedding canyons, where the giant rock formations of Independence Monument, the Pipe Organ, the Kissing Couple, Sentinel Spire, and the Praying Hands rise from the canyon floor like skyscrapers-in-stone. The canyons are also places where the cascading song of the canyon wren echoes, where small life-sustaining pools linger after summer rains, and where cottonwood trees turn golden in autumn.

Visitors might encounter mule deer, desert cottontails, antelope, ground squirrels, rock squirrels, chipmunks, and lizards. Mountain lions, midget faded rattlesnakes, and other rare or secretive members of the canyon community are seen less often. In the spring and summer, cactus, yucca, and other flowering plants bloom by the hundreds—many near springs, along the seeps in rock walls, or near canyon pools and intermittent streams. These oases of water are lush compared to sparse desert scrub life of piñon, juniper, sagebrush, mountain mahogany, and rabbitbrush that inhabits the more common arid portions of the canyons.

Magnificent views from the highland trails and Rim Rock Drive, which wind along the plateau, stretch from the colorful sheer-walled canyons and fascinating rock sculptures to the Colorado River valley (called Grand Valley), the purple-gray Book Cliffs, and the huge flat-topped mountain called Grand Mesa. The road meanders from one stunning vista to another. One of the sights is Independence Monument. It is so-named because John Otto was known to climb to the summit on the Fourth of July and plant a flag there. There are many trails of varying lengths and elevation gain in the monument, as well as world-class climbing routes. Camping, picnicking, and cycling (along the road) are also popular activities.

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Appendix F: Park Geological Setting

The Colorado Plateau and its desert landscape covers parts of Colorado, Utah, Arizona, and New Mexico, including Utah's canyonlands and the Grand Canyon. As one heads west, however, this spectacular region has its most visible beginnings on the western Grand Junction skyline in Colorado National Monument (Carpenter, 2002).

Over a period of 1.7 billion years, geologic processes have created the features at Colorado National Monument. These processes include volcanism in island arcs along the growing ancestral North American continental margin, high-grade metamorphism, several periods of mountain-building, several periods of deep erosion, deposition of marine and non-marine sediments, more uplift, and finally erosion that carved the modern landforms (Scott et al., 2001).

Colorado National Monument lies along the northeastern flank of a large topographic feature known as the Uncompahgre Plateau. It is a high, elongated plateau region that extends from Ridgeway, Colorado, northwestward to near Cisco, Utah. The metamorphosed crystalline basement rock (1.7 billion years old), as seen in the monument, underlies the entire length of the plateau, with the Triassic Chile Formation resting directly on the ancient basement rocks. There is no hint of the existence of any rocks having been deposited on the eroded basement surface between Late Precambrian and Late Triassic time, a period of some 1.5 billion years (Baars, 1998).

During Precambrian time, island arc volcanic rocks and related sediments accumulated along the continental margin. Compressive mountain building and intrusion of granitic rock and pegmatite dikes followed. During Cambrian through Mississippian time (545-320 million years ago), relatively thin marine sandstone, limestone, dolomite, and shale were deposited, covering much of the North American craton. During Pennsylvanian and Permian time (320-251.4 million years ago), Colorado was subject to a second period of compression and uplift, which formed the Ancestral Rocky Mountains. During this period of mountain building, the previously-deposited marine rocks—if ever present here—were eroded, transported, and deposited away from the monument area in great thicknesses into the Paradox Basin. Once again, the highly metamorphosed cores of ancient mountains lay exposed in the monument area.

Then deposition began again. Triassic through Cretaceous sediments were deposited over Colorado, this time under largely non-marine conditions until the Late Cretaceous seas covered the area. During the Mesozoic, non-marine sandstone and shale were deposited on the Precambrian basement rock. Most of the cross-bedded sandstone was deposited in desert conditions, and commonly shale was deposited in shallow non-marine lakes. Then the thick marine Mancos Shale and younger non-marine sandstone and shale covered these strata.

For a third time, mountain building affected Colorado. The Laramide Orogeny began in Late Cretaceous time and continued into the middle Eocene (about 50 million years ago). This mountain-building episode caused uplift, folding, and faulting in the Colorado Plateau region. Most of the present-day structural framework for Colorado National Monument was formed during the Laramide Orogeny.

After the Laramide Orogeny, during a significant part of the Cenozoic Era, great volumes of sedimentary rocks—particularly the soft, easily eroded shale—were slowly removed from the Colorado Plateau. During periods of relative tectonic quiescence, rivers in the area tended to meander and began to carve broad valleys into the areas underlain by Mancos Shale, such as Grand Valley. Regional uplift(s) in the Late Cenozoic caused rivers to entrench their meanders into the more resistant rocks beneath the Mancos Shale, forming such notable features as the Grand Canyon, Westwater Canyon, and the Goosenecks of the San Juan River.

This process of exhumation as a result of regional uplift is continuing today. Erosion of the canyons on the northeastern edge of the Uncompahgre Plateau at Colorado National Monument is beginning to remove the Mesozoic rocks from the Plateau. And for a fourth time, Precambrian rocks are being exposed. It is the canyon-cutting process that today is creating the magnificent scenery of Colorado National Monument.

Colorado National Monument's magnificent scenery is a result of the process of erosion that creates both its beauty and hazardous conditions. Intense summer thunderstorms are common and quickly produce large volumes of water that rush through the canyons of the monument. These storms erode the canyons, and flood buildings and roads built in their paths. Unstable cliffs produce rockfalls that pose a threat in areas where visitors travel and that have been destabilized during construction of Rim Rock Drive. Expansive clays, present in rocks in the monument, play a role when wetted, and enhance landslides in the area.

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Appendix G: Compilation of Notes taken during Scoping Session

September 10, 2002

Stream channel morphology and Streamflow

Issues

➤ Flash flooding and development at the mouth of canyons

➤ Make cooperative efforts with the USGS to get word out to the public because flash floods are going to happen

➤ Culverts are placed where the natural flow is; all they do is slow down the natural flow and divert flow off the road

➤ White Rocks area has had a catchment basin that was used to slow flooding in the past; it is silted up now; Park hesitates to maintain this because it changed the natural flow.

➤ UPDATE: We really don't know the intent of these [there were 2] basins. They may have been associated with bison management to provide a water source. Our hesitation isn't really with changing the natural flow, it is that they are no longer needed for bison [if that was the intent] and that they are not adequate for flood control and could actually increase flood damage if [when] stored or retarded water would breach the dam. We don't want to be responsible for increasing flood potential and creating a false sense of security with a totally inadequate structure (D. Price, personal communication, 9/24/02).

➤ Park shouldn't be altering the floodplain, rather homeowners should take responsibility for building in water courses

➤ Upstream landowners can be legally responsible for installing water diversions that change the hydrology and impact downstream property (D. Price, personal communication, 9/24/02)

Importance to ecosystem

➤ Creates canyons (e.g., No Thoroughfare Canyon)

➤ Cleanses creek beds every time there is a flood; may have an effect on exotics, also affects native vegetation

Human influences

➤ Glade Park: changes in land use outside the park may be affecting flooding potential

➤ Runoff (Rim Rock Drive and parking lots in park)

➤ Maintenance practices may be increasing erosion locally, e.g., in the maintenance area

➤ Culverts: have a nozzle effect, change output area by feet only, decrease diameter of inflow (6 foot culvert diameter)

➤ Question: What is the best way to remove material from culverts once they get plugged? Routine maintenance is needed to keep culverts clear in anticipation of flooding events.

➤ Water plant at mouth of Fruita Canyon, near west entrance may be located in hazardous area

Management significance

➤ Flash flooding is a very integrated issue and affects all divisions/units of the park

Public education

➤ Park should cooperate with the USGS, Colorado Geological Survey, and/or local geologists to develop a plan for educating the public about flash floods. The plan could be modeled after the fire community's efforts, which has been successful.

➤ Suggested event: Host a public field trip that highlights long history of flash floods in the area. Plan trip for the 25th anniversary of the large flash flood that occurred in April 1978. Invite local community, including County Commissioners.

Inventory and monitoring

➤ Streams are dry except when there are floods

➤ Gauges would be washed out during floods—Correction: There are methods that would allow for the measurement of streamflow during flood events that would likely survive a flood. USGS does this on a routine basis (P. Vonguerard, personal communication, 10/14/02)

➤ Repeat photography may be an option. Since floods will leave debris, won't need to photograph during flood event. Recommendation: Train a volunteer to take photos after each flooding event, which occur approximately 2 times per year (July-August). Geoscientist-in-the-Parks program could provide funding for camera equipment. Contact: Judy Geniac, GIP Program Manager, GRD

➤ Need to determine frequency of floods: less than an 120-year weather record

➤ An oral record could be gathered, as well as gathering information from newspaper

➤ Weather station at Visitors Center

Research
➤ Create a flash flood model and run for each drainage in COLM.

➤ This could be a GIP project. Work with local professors at Mesa State (geomorphology, hydrology, and GIS)

➤ Will need appropriate software (B. Hood, personal communication, 9/22/02)

➤ Suggest installation of crest-stage gages to supplement any modeling over the years (P. Vonguerard, personal communication, 10/14/02)

Stream sediment storage and load

Issues
➤ This geoindicator is also related to flash floods; no movement until flash flood

➤ Proxy evidence for climate change in the last 10,000 years

Resource
Desert Research Institute, Reno, Nevada http://www.dri.edu/

Slope failure

Issues
➤ Process of identifying high potential areas for slope failure, primarily along road and at overlooks, could be easily done; focus on Morrison Formation outcrops on steep dips and fault zones

➤ Rim Rock Drive: problem of rerouting the road if slope failure causes the road to fail; there may not be an easy place to reroute considering geology and wilderness areas

➤ Fire and/or increased precipitation may trigger landslides

Importance to ecosystem
➤ Can create pile of rubble that have greater permeability and porosity, e.g., at Liberty Cap trailhead

➤ Happens all over and repeatedly

➤ Creates "new" surface

➤ Landslides cover large areas

Human influences
➤ Fire may be caused by humans

➤ Traffic on road, especially large vehicles (e.g., propane trucks, school buses, tour buses) cause vibrations that affect mircrofractures in the rock

➤ Rim Rock Drive itself

Management significance
➤ Rim Rock Drive is a significant park resource; facilitates public enjoyment and the ability to view park geology

➤ Slope failure is tied to the formation of the landscape and creation of the Monument

➤ Daily maintenance issue

Inventory
➤ Identify areas of high potential for slope failure along Rim Rock Drive and overlooks with GPS and incorporate into park's GIS. Contact: Bill Hood

➤ Inventory and GIS would take the focus off 23 miles of road and allow park to focus on high potential areas

➤ Road rangers could assist in identifying cracks in the asphalt. Use GPS to locate.

Monitoring
➤ One day per year road rangers could monitor cracks that have been identified.

➤ Place stakes in landslide material along the road to detect movement/creep. Perform survey once every two years. Low cost project that would provide valuable information to park managers.

Planning
➤ If slope failure potential is recorded on a GIS layer, park would have a planning tool to be used for (1) locating "warning" signs, (2) coming up with options for rerouting road, if/when it fails

➤ Park has short-term plan for road closure but not a long-term plan if road goes out; road was closed for 1 year in the past when the area between the two west tunnels was washed out

➤ Long-term plan for road closure, rerouting, maintenance, etc. needs to be part of General Management Plan (GMP). Work with geologists, engineers, and Federal Highway Administration to plan alternatives.

➤ Plan should take into consideration the location of facilities; all facilities will soon be located on the west side of the park; moving housing because of uranium tailings

➤ Trails are not an issue like the road; trails are easily rerouted

➤Since fire plays a role in (and could trigger) landslides, slo pe failure should be part of the Fire Management Plan; potential to mitigate landslides with smaller, prescribed burns; greatest potential for slope failure is during the first year after a fire

Groundwater level

Issues

➤ Development (i.e., increased consumption) in Glade Park could affect park ecosystem, particularly seeps and springs

➤ Development in Glade Park is limited by water supply; may be able to tap into Fruita water line in the future

Importance to ecosystem

➤ Water is a rare resource and wildlife and plants, including T&E species, depend upon it

➤ Supplies seeps and springs (areas of high biodiversity)

➤ Example: In Ute Canyon, the south canyon-side gets groundwater discharge that feeds plants

➤ Very important on a local scale

Human influences

➤ Groundwater level also changes because of natural processes. The level fluctuates naturally depending on fluctuations in precipitation. It is especially noticeable after extended periods of higher or lower than normal precipitation. There is a lag time of course, because of the relatively slow movement of water through the substrate. There should be some way to model the natural fluctuations so that human use changes can be differentiated from the natural changes (T. Wylie, personal communication, 9/26/02)

Management significance

➤ Affects seeps and springs, which are a significant resource

➤ Significant for management to quantify groundwater levels to use information for planning and future decision-making

Inventory

➤ Need baseline data on groundwater levels. Potential sources of information: Local Driller and State Engineers Office

➤ Baseline data needed in order to plan for development in areas bordering park

➤ Identifying residence time (using tritium) would be useful information

➤ NPS Water Resources Division focuses on water quality (not quantity); however, USGS-WRD is doing research

➤ Need to get seeps and springs inventory into digital format; currently have hand-drawn locations on 7.5 minute topo maps (data probably collected at the same time a vegetation study in 1984)

➤ Eric Aiello has been making 3D model of the park and have acquired software to start doing some analysis on COLM watersheds (E. Aiello, personal communication, 9/23/02)

➤ Contact Judy Geniac re: GIP funding for seeps and springs project

➤ At a minimum a network of wells should be monitored at least annually but preferably quarterly or more often. USGS has capabilities to advise or participate in this activity. Another important issue would be to identify the groundwater recharge area for COLM. Determining the rate of groundwater withdrawal in the recharge area will be an important step in understanding off site development on groundwater resources of COLM (P. Vonguerard, personal communication, 10/14/02)

Monitoring

➤ Park doesn't have a well (since human consumption is from Fruita water supply) but needs to monitor groundwater level for health of the ecosystem; get permission from homeowner in Glade Park to monitor water level in private well

References

Lohman, S.W., 1965, Geology and artesian water supply of the Grand Junction area, Colorado: U.S. Geological Survey Professional Paper 451, 149p.

Lohman, S.W., 1963, Geologic map of the Grand Junction area, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-404, scale 1:31,680.

Groundwater quality

Issues

➤ Development in Glade Park (sand), which is source area for COLM; Black Ridge is also a source area

➤ Data indicates that groundwater quality in COLM meets standards

Human influences

➤ Septic systems in Glade Park could ultimately affect the park; filters through a mile of sandstone first, however

Management significance

➤ Mandated that park managers take groundwater quality into their planning and decision making

➤ Speaks to condition of resource and whole ecosystem—need to know baseline condition if water quality degrades in the future

Inventory

➤ Inventory has been performed on seeps and springs. Contact: Paul Vonguerard, USGS-WRD, Grand Junction

➤ A level one water-quality inventory was completed in 2001. An administrative report is pending. Inventory has been performed on seeps and springs. Contact: Paul Vonguerard, USGS-WRD, Grand Junction

➤ Ground-water quality information will be an important tool for understanding sources of groundwater (recharge) that supply COLM (P. Vonguerard, personal communication, 10/14/02)

Soil quality

Issues

➤ Soil quality at COLM is naturally poor but typical of areas in the Colorado Plateau

➤ Not much organic matter, poorly developed—primitive soils developed from bedrock, C-horizon only

➤ Some selenium from Mancos Shale, but not a major factor

➤ Aeolian component of soil

Importance to ecosystem

➤ Some local soil surfaces on benches

Human influences

➤ Social trails (local issue) compacting soils, e.g., No Thoroughfare Canyon, trail between Visitor Center and Book Cliffs View (overlook), and Alcove Trail

Inventory

➤ Park has recent soil survey of Mesa County (Eric Aiello, personal communication, 9/23/02)

Planning

➤ Climbing Plan: What are the affects of rock climbing on the proliferation of social trails?

Notes from October 17, 2002 correspondence with Pete Biggam

➤ Pete Biggam, Manager, NPS Soil Science Program, provided the following comments upon review of the scoping report

➤ I do not agree with many of "observations" regarding soils from the meeting, but do not feel it is my place to correct them, only comment on them

➤ I feel we need to add the definition of soil quality here to clarify the geoindicator, as it is being misused and misunderstood in the first reference under Issues; "Soil quality at COLM is naturally poor but typical of areas in the Colorado Plateau"—this is a broad generalization, and a misunderstanding of the concept of soil quality

➤ Here's the definition of soil quality that should be used—Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance the quality of water and air, and support human health and habitation. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate

➤ Soil Quality does not have a "rating" such as what was referred to as "poor" in this instance

➤ Also, in this same section, a comment is made that "Not much organic matter, poorly developed - primitive soils developed from bedrock, C -horizon only"—Again, another broad generalization that does not reflect the soils at COLM

➤ Most of the soils are influenced by aeolian parent materials,
not residuum from bedrock, and do indeed have more than just a C horizon

➤ There are also very deep, well developed soils in canyon bottoms and riparian areas

Contact

➤Pete Biggam, Soil Scientist, 303-987-6948, pete_biggam@nps.gov

Soil and sediment erosion

Issues

➤ Focus on sediment erosion (not much soil to erode), such as rockfall, sediment erosion caused by flash floods

Human influences

➤ Local significance with respect to road and trails, not a large aerial extent

➤ Road building: road cuts and increased runoff

➤ Social trails tied to increasing visitation

Management significance

➤ Erosion has created the park's landscape

➤ Obviously this is a significant process in COLM but management cannot do anything about it; process is on its own and taking care of itself

Inventory

➤ No data on rates of erosion

➤ Rates of erosion is dependent on rock type:

Least (erodible)
Precambrian
Kayenta Fm
Wingate Sandstone
Entrada Sandstone
Morrison Fm
Wanakah Fm
Mancos Shale
Most

Research

➤ See Appendix I for research proposal on valley fill, prepared by Bill Hood

Surface crusts and fissures

Issues

➤ Biotic crusts exist in upper regions, little remains in canyon areas (assume it was once there)

➤ Fissures have proved significant for preservation of paleontological resources, e.g., discovery in January 8, 2000 rockfall area

➤ Loss of the resources in canyon areas because of bison herd

Importance to ecosystem

➤ Contact expert for an opinion on the importance of crusts to COLM's ecosystem. Pete Biggam, NPS Soils Program Coordinator, pete_biggam@nps.gov, 303-987-6948 or Jayne Belnap, jayne_belnap@usgs.gov, 435-719-2333

➤ NOTE: Email (9/18/02) from Jayne Belnap stressed the significance of soil crusts to the ecosystem in COLM and their prevalence throughout the park.

Human influences

➤ 1930s—herd of bison (up to 60 head) grazed throughout the canyon areas; ended in 1980s

➤ Herd was an attempt to get visitors to come to COLM

➤ Fence was built to keep bison in

➤ Cactus survived

➤ Permanent damage of crusts occurred in CCC camps

➤ If trampled, then susceptible to wind erosion

Management significance

➤ Important to have inventory for placement of trails

➤ Important theme for visitor education

Inventory

➤ Include inventory of biotic crusts in the vegetation mapping/inventory

➤ Incorporate inventory into GIS.

Contact:

➤ Eric Aiello, Eric_Aiello@nps.gov, 970 -242-7385

➤ 1984—Michelle Huffman did a vegetation study that included soil crusts (311 plots), although not a soil survey, could provide useful information,

Monitoring

➤ Question: After an inventory is completed, should monitoring be done?

Planning

➤ Link to Fire Management Plan—greatest amount of crusts occur where there is the greatest amount of pinyon and juniper

Surface water quality (and level)

Issues

➤ The group decided to add "level" to this geoindicator. Quantity is more of an issue for COLM than quality, which is good.

Importance to ecosystem

➤ Some pools have water in them all year, such as below (intermittent) waterfalls, e.g., lower waterfalls in No Thoroughfare Canyon

➤ Potholes are prevalent. Microbiota in these potholes spring up quickly after a rain.

➤ Surface water is rainfall dependent

➤ Wildlife water supply; larger mammals will travel to Colorado River for water, smaller mammals get water from plants

➤ Spring runoff is typically the only time actually streams flow

Human influence

➤ Hikers may have a significant impact on limited surface water resource

Seismicity

Issues

➤ Magnitude 2 earthquake is typical for the area

➤ There is a seismic monitoring station at Mesa State

➤ Area appears to be quite stable, sometimes a "wiggle" will be recorded

➤ Potential for seismic activity because of isostatic unloading through erosion of the last million years and faults, but no current activity

Monitoring

➤ Mesa State College would like to have a seismic station located in the park. Need three stations to get accurate local information. Mesa State staff would monitor and maintain. Contact: Verner Johnson, (contact via email preferred), Mesa State Geoscience Program

➤ Need a computer (used) in order to monitor. Natural Resource Program Center may be able to donate.

➤ Monitoring station could be located in maintenance or housing area

Management significance

➤ Management significance is low, but the addition of a seismic station in the park would encourage collaboration between the park and the local academic community, i.e., facilitate a good working relationship

Surface displacement

Issues

➤ Ancient movement along faults, no current movement.

➤ May be some isostatic rebound (See Seismicity geoindicator)

Wetlands

Importance to ecosystem

➤ Greater plant and animal diversity in wetland areas

➤ Provide cooler temperatures

➤ Hanging gardens, e.g., in upper No Thoroughfare Canyon

➤ There is a lithologic control on wetlands

➤ The scarcity of wetlands increases their importance to wildlife

Human influences

➤ Leakage along old pipeline when Dave Price first arrived in COLM

➤ Created two reservoirs for Fruita water use, no longer use

➤ CCC camp dammed spring in Monument Canyon

➤ Trails in canyons with wetlands

Management significance

➤ Issue if water line is ever reactivated (if more water is needed in Fruita)

➤ Damage to resource that would accompany reactivation, which would require construction, would be great

Inventory

1. Two wetland areas:
    a. Upper Ute Canyon
        (1) Several types of willows
        (2) Classified as wetland by U.S. Fish and Wildlife Service
        (3) Lithologic control: Precambrian rocks dam area
    b. Upper No Thoroughfare Canyon
        (1) Hanging gardens, aspens, and Douglas fir
        (2) Not designated a wetland
        (3) Pristine area; elk were brought in, but have gone

➤ Wetlands total about 20 acres in size

➤ Wetlands will be inventoried through vegetation mapping program using GIS. Need to be mapped, ground truthed, and digitized.

➤ Current information gained through survey of tamarisk

Reference:

Cowardian, Lewis M., Virginia Carter, Francis C. Golet, and Edward T. LaRoe, Classification of Wetlands and Deepwater Habitats of the United States, U.S. Department of the Interior, Fish and Wildlife Service, FWS/OBS -79/31, December, 1979.

Dune formation and reactivation

Issues

➤ Small, isolated, localized dunes, stabilized by vegetation

➤ Exist at end points/projection of Entrada Formation

➤ Fire could have great impact on dune activation by destroying vegetation

Human influences

➤ Trampling by visitors causes remobilization

Inventory
➤ Dunes have been identified on geologic map (Qe) if ever needed for inventory purposes

➤ Dunes can be seen in aerial photographs

Dust storm magnitude, duration, and frequency

Issues
➤ Oral history: dust storms more frequent in the 1940s. Question: What is the norm? Is 1940s situation "normal"?

➤ Occurrence of dust storms more prevalent in Grand Valley than in canyons; some dust may be transported into the park

➤ Question: What is the source area for aeolian sediment in the park? Soils have sand vs. silt from Mancos Shale in the valley

➤ Visibility: dust storms affect visibility in the valley, but rarely along Rim Rock Drive

➤ (Wind- blown) Calcium carbonate influences what little soil there is in the park; source area is probably from San Rafael Desert in Utah

Management significance
➤ There is scientific value but a low priority with respect to daily management concern

Monitoring
➤ Mesa State College (Geomorphology) would be interested in having a monitoring station in COLM

➤ They would need a collection permit and a sheltered spot to put traps, which they would do collections on once per year

Wind erosion

Importance to ecosystem
➤ Water is primary erosional agent, not wind

➤ Process has been going on for thousands of years

➤ Rock faces have holes that may be enhanced by wind erosion (and ultimately enhance arches, natural bridges), but probably more structural dependent

Human influences
➤ Grazing is no longer occurring in the park, very little occurs in Glade Park
➤ Cheat grass is influenced by fire; small seeds that go everywhere

➤ No identifiable park practices that would be encouraging wind erosion

Other issues

➤ Park would like to use geology to identify paleontological and archeological sites

➤ Paleo Contacts: John Foster, Museum of Western Colorado, jfoster@westcomuseum.org, 970-858-7282; Greg McDonald, Geologic Resources Division, Greg_McDonald@nps.gov, 303-969-2821

➤ Possible Archeology Contact: Mesa Verde National Park
Appendix H: Compilation of Notes taken during Opening Session and Field Trip

Appendix H:
Compilation of notes taken during Opening Session and Field Trip

September 9, 2002
Opening Session (morning)

The scoping meeting grew out of a technical assistance request that included four items:

(1) Human influences/outside influences
(2) Flash floods/geohazards
(3) Research to better understand geologic resources
(4) Geologist-in-the-Parks (GIP) request

Bob Higgins saw a connection between the technical assistance request and geoindicators and suggested a meeting.

Background inventory: already have a geologic map; Bill Hood was on the mapping team

Boundary issues
➤ Park is dealing with a variety of boundary issues: urban interface/development, wilderness, and other land management agency (Bureau of Land Management)

➤ Coordination with BLM: (1) trails (dog use, horse use), (2) fire policy implementation (e.g., fuel reduction), (3) decrease in grazing and taking down fences, (3) interagency interpretation (consistent information, sharing staff and facilities)

General Management Plan (Suzy Stutzman)
➤ Park is collaborating on General Management Plan (GMP) with the BLM because of their shared concerns for ecosystem management (holistic approach), visitor use, and paleontological resources

➤ GMP process includes: public scoping, alternatives, outcomes focus (i.e., manage toward), management prescriptions—what do we want particular parts (and whole) of the park to "do"/"be"?

Park overview (Ron Young) (See also Appendix F)
➤ Canyons, red rocks

➤ 1911—park was set aside for extraordinary examples of erosion for scientific purposes

➤ Most visitors are here for a couple of hours

➤ Interpretation strives to make connection for visitors with geology (although it is much easier to interpret birds, mammals, and plants, COLM focuses on geology)

➤ Half a million visitors per year; greatest law enforcement problems are with those that are "driving through"

➤ COLM is the third most poverty-stricken park in the Intermountain Region; there is no seasonal interpretive staff

➤ Issues for Interpretation: making an "emotional" connection for visitors; personnel needed for training and auditing

➤ Issues for Law Enforcement (re: geology): Rim Rock Drive, graffiti, vandalism (an arch was destroyed)

➤ Additional issues: (1) sand application on road, exotic weed seeds with gravel, and (2) growth of Grand Junction (high visitation in spring and fall)

➤ VIPs/Geologists (Bill Hood and Don Baars) work with staff and students at Mesa State on behalf of COLM

Resource issues (Dave Price)
➤ How do park managers protect erosion (enabling legislation)?

➤ Rim Rock Drive—facilitate ways for public to see resources vs. maintenance

➤ Public enjoyment (access) vs. protection

➤ Park is managed as Wilderness

➤ Servicewide question: How do we manage for change?

➤ Issues re: human impacts: (1) social trails (not quantified); (2) flash flooding effects on neighbors (park neighbors have made it an issue by building at the mouth of canyons, i.e., insist that floods are coming through canyons that are in the park and would like to hold park responsible for flood damage to homes; (3) development in Glade Park, which is above the park; development is limited by water availability at this point; water quality (e.g., runoff) and water level (e.g., human consumption/use) are main issues with this development—will this affect seeps, springs, and hanging gardens?

➤ Surface water quality is good in COLM

➤ Park management would like to use geology to identify habitats for Threatened & Endangered Species, cultural resources (smaller scale than Mesa Verde, but still a valuable resource), and protection options with respect to high erosion rates.

➤ Identify maintenance practices that may be detrimental

➤ Paleo Inventory starts September 2003 through 2004; Contact: Greg McDonald (GRD Paleontologist)

➤ Erosion and exposure of paleo and archeological resources is a concern

➤ GPRA—does not encourage long-term funding (monitoring?) because law was set up as reaching shorter-term goals

➤ Fire Management Plan: study fire history using geology; plan is being developed; need to look at impact to soils

➤ Research Requests: Park wants to switch from response to research request to soliciting needed research; park gets 6-8 research requests/year with approx. 3 on geology

Water quality (Paul Vonguerard)

➤ Inventory on seeps and springs

➤ Water is exceeding standards

➤ Age: pre or post bomb

Rim Rock Drive

➤ Big issue: rock failure on Rim Rock Drive, no other place to route road

➤ Road has links to Chamber of Commerce and public process (planning)

➤ Monitoring of tunnels with stress meter

➤ Big rockfall on January 8, 2000

➤ Road failure in 1960s

➤ Need to tie road issues into GIS for predictive model

➤ Park responsible for road from boundary to boundary; Little Park Rd—not in park jurisdiction; Park must maintain portion of road to Glade Park that is in the park boundary

➤ Rockfalls are daily maintenance issue; current practice is to dump rocks over the side of the road—what is this practice doing to ecosystem? [e.g., dust (identified as fire in town)]

➤ Fill between tunnels was washed out during a flash flood

➤ Fill was brought in, has no "geologic integrity"

➤ Conflict with users on road: commercial, cyclists (no mountain biking permitted on trails), cars

User groups

➤ Horse use: not a strong historical use; there have been better places to go; beginning to have inquiries about this "neglect"

➤ School groups (especially Vail and Eagle): K-12 camping, used heavily in May

➤ Geology Field Camps: could find statistics on Educational Fee Waivers, if park or Service wanted to pursue theme of National Parks for Higher Education

Geology overview (Bill Hood) (See also Appendix E)

COLM is on the edge of the Colorado Plateau and has "typical" geology of the Colorado Plateau

1. **Stratigraphy**
   a. Beds are mostly flat-lying
   b. Mancos Shale (Cretaceous) - ~4,500 ft. thick
   c. Pre-Cambrian (mostly dark gray gneiss)
      (1) Rose about 1,500 feet along fault
      (2) Uplift part of the Uncompahgre Uplift (as is the Black Canyon of the Gunnison)
      (3) ~1.7 billion yrs. old
         d. Chinle - Triassic
         e. Lower Kayenta Formation - resistant ledge and cliff former
         f. Lava flows (10.4 Ma)
         g. Book Cliffs (delta deposits)
         h. 10 million years ago: area was "flat as a pancake"; lava flows spilled out onto flat surface and preserved underlying landscape, then eroded by Colorado River (at different channel)

2. **Tectonics**
   a. World-class monocline exposure (formerly called "Lizard Canyon Monocline"); drapes over Precambrian structure
   b. Plate movement
      (1) Rocks reflect the movement of the North American plate from near the equator to present location; tropics to temperate climates in rock record; use magnetite in rock to measure inclination of past magnetic field to find relationship to equator—high interpretive value (also beach and dunes here)
      (2) Laterite layer near Moab
      (3) No laterite layer in COLM, but upper part of Pre-C is highly weathered
      (4) Wingate represents a more desert environment as plate moved north
      (5) Morrison (J) and Cretaceous rock deposited near present location
      (6) Uplift 65 million years ago
         (a) Fault in front on Monument
         (b) Uplifted Precambrian rocks (resistant) above Mancos Shale (easily eroded) as tributary streams cut down through sandstone to Precambrian rocks to create "hanging canyons"

(c) Created monoclines (textbook examples)
(7) 300 million years ago, Pennsylvanian Period: COLM is "center" of uplift of Ancestral Rockies; prior to uplift, this area was at sea level; source area of sediment for Paradox and Eagle basins; shredded sediment = unconformity

3. Colorado River (used to be called the Grand River, hence Grand Valley)

a. Colorado R. gravels found on Grand Mesa, ~5,000 ft. above present river location (erosion ~6"/1,000 yrs.)
b. Debate as to Colorado River down-cutting
(1) Was area already uplifted & Colorado River began down-cutting, or
(2) Did uplift begin 8-10 million years ago & then river eroded down?

4. Unconformity

a. Gap in geologic record (1.5 billion years) between Precambrian (1.7 billion years old) and Chinle Formation (210 million years old)
b. 50-foot weathering zone right above Precambrian; look at weathered zone to tell story to visitors

5. Specific Geologic Issues

a. Landslide potential because of expandable clay minerals (Morrison Formation—Brushy Basin and Salt Wash Members—and Wanakah) and groundwater; wet conditions could trigger landsliding
b. Rockfalls: loose sand along the lower boundary of Entrada Formation (contact w/ Kayenta Formation) moved out by groundwater; sand has been blown into dunes
c. Accumulation of sediment (pause in canyon cutting between 10,000 and 300 years ago) that has charcoal (either washed or blown in)—provide fire frequency and climate change history of 10,000 year period
d. Windblown carbonates (probably from San Rafael Desert in Utah) created carbonate filling of cracks and interstices; associated with snail fossils
e. Glacial history: Grand Mesa was glaciated; Unaweep Canyon is being debated

6. Water

a. Much of Glade Park area drains to the west, away from the park
b. Fruita gets water from reservoirs south and west of park
c. Probably more but smaller reservoirs will be built or enlarged for increased water supply capacity
d. Seeps and springs at the contact of the Wingate Sandstone and Chinle; also at Kayenta-Entrada-Wanakah contacts
e. Hanging gardens (association between geology, hydrology, and biology); typically in Wingate Formation

7. Research

a. Valley fill [land snails using oxygen isotopes, charcoal, small mammals (?), pollen in pack rat middens and lake cores]—integrated research proposal
b. Evidence of human habitation (scrapers) with charcoal, dated at ~5,000 yrs.

Flash floods

➤ Long record of flash floods: graded bedding in canyon walls (e.g., No Thoroughfare Canyon) to recent debris on cottonwoods

➤ Issue: development at canyon mouths, building on alluvial fans that are covered by wind- blown sediment makes fans difficult to identify

➤ Recurrence interval not identified; need data; could do modeling (Bill Hood and Don Baars)

➤ Don't know what 100- and 1,000-year events look like

➤ Need to identify kinds of extreme storms (What are they? When are they? Cause?—snowmelt peaks, rainfall peaks (monsoons, hurricanes)

➤ COLM is too far north for major monsoonal flow; rainfall is more spring and summer event

➤ Quick run-off creates recreational opportunity, i.e., looking for waterfalls

Fossils

➤ No fossils found in Wingate Sandstone; some in Chinle

➤ Trackways (dinosaur and mammal) at base of Wingate and top of Chinle

➤ Inventory needed; incorporate findings into interpretation, maintenance (e.g., not toss it over the edge, grading the road), law enforcement, partnerships with BLM

➤ Removing/curating fossils near RRD and areas frequented by visitors is an issue

➤ Monitoring (after inventory) on cyclic intervals

➤ Work with John Foster at Museum of Western Colorado (Dinosaur Museum) with respect to curatorial needs and repository

➤ Seasonal curator (Judy) at COLM is leaving

➤ Curatorial and repository needs in paleo could be coordinated Network-wide; also interagency (with BLM)

➤ GRD has written a PD for a paleontologist at the Region

Field Trip (afternoon)

Stop 1: Book Cliff View

Topics: rock formations, plate tectonics, sedimentary structures, irrigation, biotic crusts, social trails

➤ Rocks seen at stop: Precambrian metamorphic (at bottom of canyon), Chinle (bright red), Wingate (wall that we see), Kayenta (microscopic quartz crystals, braided stream deposit), Entrada (salmon-colored cliff that we drove by)

➤ Fossil dinosaur tracks, root traces, burrows, and stromatolites occur near the Chinle-Wingate contact

➤ Area displays plate movement: lack of red Paleozoic rocks equates to mountain range (Ancestral Rockies, 30-50 Ma) that was uplifted and eroded some 300-220 Ma; Chinle's red color indicates formation a few degrees (5 to 15 degrees) north of the equator—tropical with a seasonal dry period

➤ Irrigated area (40 inches/year) vs. 6-8 inches/year in non-irrigated areas

➤ Faulting: (1) along Precambrian, (2) microfractures in Wingate, (3) reactivated faults during Laramide Orogeny (70 to 40 Ma)

➤ Concern for biotic crusts (although not as developed as in Arches and Canyonlands)

➤ Social Trails: overlooks, to access climbing routes on Independence Monument, Devils Kitchen (picnic area and rock formations)—baseline data needed for potential climbing areas (set up data points with repeat photography)

Drive-by
Unconformity and bulge of clay-rich area in roadcut/ landslide-waiting-to-happen for wetter conditions, erosion undercutting sandstone upon which road was built, culverts, Kayenta Formation (many small crossbeds)

Stop 2: Independence Monument View
Topics: erosion, landslides, climbing

➤ Monument is remains of wall between Wedding and Monument Canyons

➤ Landslides: related to fire and climate change

➤ Law enforcement/search and rescue of climbers: parks works with local rescuers

Drive-by
➤ Half Tunnel—In 1930s (around Christmas time) during road construction, a large slab of rock broke off, killing 13 people

➤ Black Ridge—antennae within view of road—important communication relay for Grand Valley

Stop 3: Artists Point
Topic: rockfall

➤ Wanakah Formation covered with debris, rockfall issue, constant maintenance issue
➤ Ripple marks
➤ Green = lake deposit

Stop 4: Liberty Cap Trailhead
Topics: rockfall, rock weathering, Holocene bones

➤ Rockfall occurred on January 8, 2000

➤ Jointing caused rock to topple forward; trees thrown from top of cliff

➤ Quick rate of weathering or rocks

➤ 15-20 foot high pile of rock

➤ Fissure filled with Holocene bone (bison, antelope) was exposed after landslide event; Contact: Jim Mead at NAU; also Indian campground (overlap with archeological research), pack rat (possible causes of bones in fissure)

Stop 5: No Thoroughfare Canyon View
Topics: development on the edge of wilderness area, canyon fill, coalbed methane drilling, mining

➤ Correction: No coal in the area—except for the Dakota Formation, which is too shallow for drilling—so no coalbed methane drilling (D. Baars, personal communication, 9/24/02)

➤ Correction: Drilling proposed from Grand Mesa, visible from stop, very controversial (B. Hood, personal communication, 9/22/02)

➤ No Thoroughfare Canyon is a wilderness area; private land abuts park, no BLM buffer in this area

➤ Location for integrated research: canyon fill (40 feet thick, charcoal, land snails, pollen, etc.)

➤ Interpretation of fill as a delta

➤ Mining: copper show (Wedding Canyon), gravel (river valley), prospecting for gold (Kodels Canyon)

➤ High levels of selenium in Morrison Formation—issue of Clean Water Act

Stop 6: Serpents Trail
Topics: flash floods, building at mouth of canyon/ in the floodplain

➤ Drainage area is approximately 2 mi^2 with small funnel/slot for flood waters to shoot through; houses built at mouth of slot

➤ Building on alluvial fan, which is disguised by wind-blown sand

➤ Instructive stop for students (and County Commissioners?)

Stop 7: Devils Kitchen-No Thoroughfare Canyon
Topics: history of flash floods

➤ Series of cut-and-fill, cut-and-fill, … in the last 10,000 years

➤ Processes that has been going on in this canyon have been going on for thousands of years

➤ Three flash flood deposits preserved in canyon wall, with wind-blown sediment on top; graded therefore not debris flow

➤ Typical flash flood operation in this stream

Notes from October 17, 2002 correspondence with Bill Hood
➤ The sand is local, being derived mainly from material that washed out of the canyons onto the alluvial fans

➤ I suspect from the distribution pattern of the sand (just eyeballing it; I haven't mapped it) that some may have come from the floodplain of the Colorado River

➤ The carbonate cementing material, on the other hand, is a puzzle—there is hardly any local carbonate rock—just a few thin layers in the lowermost Morrison

➤ The soils professor at Mesa State College thinks that it has to be brought in as wind-blown dust; I pretty much agree with that hypothesis although it hasn't been tested

➤ The sand, mainly quartz as mentioned, moves near the ground but the carbonate would move as wind-borne dust particles, much finer than sand, as such they could be from tens or hundreds of miles away. (Last winter we had a heavy haze in the valley that originated as a dust storm in China!)

➤ The key to identifying the sources of wind- deposited sediment is to set up a series of sediment traps at different locations and elevations around the monument and to do a careful mineralogical study of the sediment collected

Appendix I: Proposal for Study of Valley Fill

Project Description -
What is this project all about? Concisely describe what is to be accomplished. Where and when it is to be accomplished. (< 2,000 characters)

Title
Deciphering a 10,000-year record of climate change, fires, sedimentation rates and biotic response.

This project is an integrated study of the valley fill in upper No Thoroughfare Canyon in Colorado National Monument. Radiocarbon dating indicates that the deposition of the valley fill began about 10,000 years ago and ended only a few hundred years ago, spanning essentially all of Holocene time. The presence of the fill indicates that two major climate changes have occurred in the monument. Numerous layers within the fill contain grains of charcoal that originated from nearby upland fires. This study would first systematically sample the valley fill and date the charcoal layers in order to provide a precise age and stratigraphic framework to which other parts of the study can be related. Dating of the charcoal layers will provide a history of upland fires in the region. Oxygen isotope analysis of the abundant land snail shells that are preserved in the sediment will provide a record of temperature variation during this time. Grain-size and mineralogical analysis of the sediment will provide clues as to the relative amount of wind-blown vs. stream deposited material, which provides additional information about climate. Analysis of pollen and animal remains, assuming these are preserved in the sediment, will provide information about biotic response to the changes in climate. The project is estimated to take three years.

Project Justification
Concisely and accurately describe why this project is needed. (± 4,000 characters)

During a time when of increasing concerned about the impact of mankind on climate, it is important to have some baseline data as to what climate was like before the industrial age. Such a record is preserved in the sediment of No Thoroughfare Canyon. Climate has directly affected the erosional behavior of No Thoroughfare Creek, from erosion to deposition to erosion again. This study will help us understand why this stream, and by analogy the other streams of the monument, behave as they do. The record of fire frequency preserved as charcoal-containing layers will assist land managers in planning for potential future fires. Calculated sedimentation rates can provide an estimate of the erosion response of nearby land to past fires, which would be helpful in deciding how to respond to restoration after a fire. Any pollen preserved in the sediment will provide knowledge of the plant community, its response to the climate change and possibly its response to fires. A 5,000-year-old artifact found in the sediment shows that humans lived in the area and more artifacts may be found during the study, thereby adding to our knowledge of early American habitation in this area.

Project Results
What benefits will be gained from completing this project? What quantifiable output will result from this project being completed? Has this project helped the park to achieve a GPRA goal? Also, indicate specifically how park operational efficiency will be enhanced. (± 4,000 characters)

Results of the project will influence several areas. First, knowledge of Holocene climate will be of general scientific and public interest but more important, it will provide insight into the behavior of No Thoroughfare Creek. The stream largely erodes by flash floods today but the valley fill suggests that they may not have been as important in the past. Knowledge of how and why No Thoroughfare Creek has changed from erosion to deposition and back again will help Resource Management in planning how to manage an area set aside to preserve outstanding examples of erosion. Documentation of the existence of flash floods in the past will be most helpful to management in educating the public of the dangers inherent in building at the mouths of the park's canyons. Second, information on fire frequency will benefit land managers in developing fire management plans. There haven't been any large fires in the monument during 85 years since it was formed. Have we been lucky or is this to be expected? The answer to this might change how we manage for fires. Finally, information on climate change and the physical and biological response to it would be of great value to the interpretative program and help motivate the public to assist in the preservation of this outstanding area.

Cost Estimate -
The total cost of this project will be about $58,000 over three years. Direct costs for AMS C-14 dating of charcoal, oxygen isotope analyses, lab supplies, etc. will be about $32,000. Student labor will add $10,000. Two research assistantships, required for the biologic part of the study, will add another $16,000.